UNIVERSITY OF ALBERTA

THE RELATIONSHIP OF MAXIMAL OXYGEN INTAKE TO BODY COMPOSITION AND TOTAL BODY WEIGHT IN ACTIVE MALES

A THESIS

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APPROVAL SHEET

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Relationship of Maximal Oxygen Intake To Body Composition And Total Body Weight In Active Males" submitted by L. Lee Coyne in partial fulfilment of the requirements for the degree of Master of Arts.

ABSTRACT

The purpose of this study was to investigate the relationship of maximal oxygen intake to total body weight, fat-free body weight and total body fat in active males. Thirty male subjects at the University of Alberta, ranging in age from 19 to 34 years, participated in the study. The maximal oxygen intake was determined by treadmill running. The body composition measures were determined by the water immersion densitometry method and per cent body fat was estimated by the formula of Keys and Brozek.

Data were analyzed by the stepwise procedure for multiple regression and the _t_ ratio tested the significance of the beta coefficient computed for each variable.

The fat-free body weight correlated $r = 0.39$ with the maximal oxygen intake. This correlation coefficient was statistically significant at the .05 level of confidence. Other measures of body mass and body composition did not show a statistically significant relationship with the maximal oxygen intake. The fat-free body weight accounted for 15.76 per cent of the total variance of the maximal oxygen intake, while the total body fat and the total body weight accounted for an additional 8.06 per cent and 4.35 per cent respectively. A multiple correlation analysis revealed that the three body composition and body weight measures correlated 0.531 with the maximal oxygen intake. This correlation coefficient was statistically significant at the .05 level of confidence.

Within the limitations of the study it was concluded that:

1. the fat-free body weight was the best maximal metabolic reference standard of those measured in active males;
2. a more satisfactory estimate of the maximal oxygen intake would result from the inclusion of the fat-free body weight, total body fat and total body weight instead of the fat-free body weight alone;
3. a rigid interpretation of results using the formula of Keys and Brozek for per cent body fat estimates, is apparently limited in studies involving trained subjects.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction. Maximal oxygen consumption in liters per minute has been generally used as an objective measure of man's maximal cardio-respiratory performance for set conditions of work (1,2,3,4,5,6,7,). That is, a measure of maximal oxygen consumption has been used as an indication of the performance of the heart, of the amount of oxygen that can be delivered to the tissues and of the amount of oxygen the tissues can extract from the blood. It is not clear whether factors other than circulation affect this measure.

The metabolic cost of work, which is indirectly measured in terms of oxygen consumption, is traditionally expressed in terms of body weight or sometimes as surface area. These measures are based on the assumption that oxygen intake and body weight or surface area, are related. However, it is well known that men having the same weight or surface area may differ widely in body composition, particularly in fat content.

The relationship of maximal oxygen consumption to measures of body composition has been previously investigated by von Döblen (8), Buskirk (4), Buskirk and Taylor (5), Welch *et al.*(16) and Dempsey (9). It was reported in four of these investigations, using sedentary men as subjects, that there was a higher relationship between maximal oxygen consumption and fat-free body weight, than other estimates of body composition. Buskirk and Taylor (5), however, found that this relationship did not

hold true in highly trained subjects.

The Problem. The purpose of this study, then is to investigate the relationship of maximal oxygen intake to total body weight, fat-free body weight and total body fat of individuals involved in a regular training regimen.

In the problem, the null hypothesis asserts that maximal oxygen intake is not related to total body weight, fat-free body weight and total body fat.

The alternate hypothesis asserts that maximal oxygen intake is related to the three variables of total body weight, fat-free body weight and total body fat.

Subsidary Problem. Also investigated is heart rate behavior during the maximal oxygen intake test and the relationship of heart rate to maximal oxygen intake.

Limitations of the Study.

1. The study is limited to 30 active male university students and staff members, all of whom train for a specific athletic activity, participate regularly in a specific athletic activity, or participate regularly in various athletic activities.
2. The study does not include any sedentary subjects.
3. Only the parameters stated in the problem and sub-problem are considered.
4. The laboratory environment is not controlled and temperature and humidity will vary from day to day.
5. The hydrostatic weighing is carried out with the subjects

at full inspiration only.

6. Lung volumes, used for the correction of body weight in water, are determined on land and not at the time of weighing.

Definition of Terms.

Maximal Oxygen Intake. The maximal oxygen intake is a a measure of the maximal capacity of the cardiovascular-respiratory system to carry oxygen to the working tissues and for these tissues to use the oxygen (5:72).

Obesity Tissue. Obesity tissue or adipose tissue is the tissue gained or lost by experimental over-eating or caloric restriction. It is composed (from densitometric analysis) of 62 per cent fat, 31 per cent extra-cellular fluid and 7 per cent cellular matter. It has a density of 0.9478 (10:293).

Body Fat. Body fat is a chemical compound (lipoid), insoluble in water, golden yellow in color and with a density of 0.9007 at 36^{o}C. It is stored in the fat depots and comprises 62 per cent of obesity tissue (10:271).

Fat-free Body Weight. The fat-free body weight is equal to the total body weight, minus the weight of the fat portion of obesity tissue (10:269).

Lean Body Mass. The lean body mass, or non-obesity tissue, is equal to total body weight minus the weight of the obesity tissue (11:585).

"Active Tissue" Mass. The "active tissue" mass is equal to the total body weight minus the weight of fat, extracellular

water and bone (10:246).

Active Males. Active males, for this study, are men taking part in regular vigorous physical activity at least four days per week, one hour per day.

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CHAPTER II

REVIEW OF THE LITERATURE

The Maximal Oxygen Intake. The maximal oxygen intake has been described by Hill (1) as a point which is an apparent "steady state" during muscular exercise in which the oxygen intake is constant. He further added that the oxygen intake may attain this maximum and remain constant because the circulatory and respiratory systems have reached the limits of their capacities.

The determination of the maximal oxygen intake has been labelled by Taylor and Brozek (2) as the best available test, on theoretical grounds, of the maximal function of the cardiovascular-respiratory system. They believe the results to be a relatively constant characteristic of an individual and more indicative of true change in cardiovascular performance than other tests designed for a similar purpose.

The maximal oxygen intake has been used extensively as a cardiovascular-respiratory function test. Herbst (cited in 3) studied the maximal oxygen intake of patients with cardiovascular disorders and Knipping (cited in 3) investigated the maximal oxygen intake in conjunction with respiratory disorders. The maximal oxygen intake has also been studied in a number of experimentally imposed stress conditions, such as semi-starvation by Keys *et al*. (4), experimental malaria by Henschel *et al*. (5) and bed rest by Taylor *et al*. (6).

Variation in Maximal Oxygen Intake. The interindividual

variation between normal individuals in maximal oxygen intake is considerable. Robinson (7) found a range of maximal oxygen intake of 0.80 to 4.50 liters per minute in males ranging in age from 6 to 91 years. In a previous study, Robinson et al. (8) found the maximal oxygen intake of an outstanding distance runner to be 5.35 liters per minute. To date, this is the largest reported value in the literature. Astrand (cited in 9) reported an even lower maximal oxygen intake than that of Robinson (7). He found a four year old girl who had a maximal oxygen intake of 0.74 liters per minute.

The factors investigated in relation to the maximal oxygen intake, in an attempt to account for the wide variability of results, have been age, sex, training, body weight, height, surface area, measures of body composition, cardiovascular factors, respiratory factors and various pathological conditions.

Astrand (cited in 9) reported high correlations between the maximal oxygen intake and age, body weight, height and surface area. This accounts for some of the variation of the maximal oxygen intake between individuals, but actually it is only small because of the high intercorrelations between age, height, weight and surface area.

If the age range is reduced, the interindividual variation is also reduced, as is shown by considering males between the ages of 18 and 35 years in the studies by Robinson (7), Robinson et al. (8) and Astrand (cited in 9). The range was 2.56 to 5.35 liters per minute.

Factors Limiting Maximal Oxygen Intake. The limiting factors for the maximal oxygen intake in normal subjects are not exactly clear. Hill (1) has stated that the maximal oxygen intake is attained: "... merely because it cannot go any higher owing to the limitations of the circulatory and respiratory system." Bainbridge (10) has placed a great deal of emphasis on the capacity of the heart to pump blood. However, Taylor (11) and Buskirk (3) believe that in many work situations, a limiting factor may be the size of the vascular bed in the active muscles.

Evidence in support of this view was found by Christensen (cited in 11) who exercised a subject on an ergometer at a maximal level with the arms alone. The resultant oxygen intake was 2.9 liters per minute. When the same subject worked at a maximal level on a bicycle ergometer, an oxygen intake of 4.47 liters per minute was obtained. This suggests that the muscle mass involved in the work is of some consequence.

Further support of this evidence is cited by Astrand (cited in 9) and by Christensen and Hogberg (12). These investigators found higher oxygen intakes in cross-country skiing than in cycling or running for the same subjects. An explanation offered was that during cross-country skiing the arm and back muscles must work as well as the legs.

Another illustration is the finding of Buskirk (3) and of Taylor, Buskirk and Henschel (13), that a larger oxygen intake was consistently obtained when simultaneous arm and leg work

was performed during the treadmill run. This additional work increased the maximal oxygen intake by 200 to 250 c.c. per minute. Taylor added (11:147) that such evidence appears to suggest that after a maximal oxygen intake has been reached under a given set of conditions, if more muscles are brought into play, the heart can increase the cardiac output and consequently, the oxygen consumption. Mitchell, Sproule and Chapman (14) found the maximal oxygen intake was dependent on both cardiac output and arteriovenous oxygen difference.

Training and Maximal Oxygen Intake. The effect of trainig and its relationship to the maximal oxygen intake have been discussed in a further attempt to account for the variability of this measure. As was previously mentioned, the highest recorded maximum oxygen consumption (5.35 liters per minute) was reported by Robinson *et al.* (8) on a 1936 Olympic runner. Karpovich reported (15) that an untrained man may have a maximal oxygen consumption of 2 liters per minute and a trained athlete may double this amount. Astrand explained (cited in 9) that the difference in maximal oxygen intake between his experiments and those of Robinson (7) - 59 c.c. per kilogram per minute and 49 c.c. per kilogram per minute respectively - was due to the superior condition of the subjects, all of whom were physical education students. Astrand reported (cited in 9) that the highest oxygen intake values for males were obtained on elite athletes in training. Morehouse and Miller claimed (16) that athletes in training

possess the capacity for obtaining a higher oxygen intake than untrained men. Knehr _et al_. (17) studied the ability to increase the maximal oxygen intake through training. They found about a 7 per cent increase (240 c.c.) in the maximal oxygen intake for the 14 men studied over a six month training period. In a similar study, Robinson found (18) a 16 per cent increase with prolonged training for middle distance running. Buskirk (3), Buskirk and Taylor (19) and Dempsey (20), all found higher maximal oxygen intakes in individuals undergoing regular physical exercise programs.

Taylor _et al_. (6) found that if de-conditioning is brought about by placing an otherwise healthy man in bed for three weeks, the maximal oxygen intake is decreased by roughly 15 per cent. Henschel _et al_. (5) found that de-conditioning as the result of experimental malaria caused an 18 per cent decline of the maximal oxygen intake.

Body Weight and Maximal Oxygen intake. The maximal oxygen intake has frequently been related to body weight. When the maximal oxygen intake is expressed in cubic centimeters per kilogram of body weight, the range of values reported in the literature was from 29.6 c.c. per kilogram per minute in a young women, as reported by Metheny _et al_. (21) and 69.3 c.c. per kilogram per minute in a cross-country skier, as reported by Christensen (12). Robinson _et al_. (8) showed from their data that if the highly trained runner, used as a subject, had weighed 70 kilograms, he would have used 75 c.c. per kilogram

of body weight per minute.

It has been pointed out by Taylor (11) that the maximal oxygen intake per kilogram of body weight is a good measure of the oxidative energy available for moving a man from place to place. Buskirk (3), Buskirk and Taylor (19) and Welch *et al.* (22) have found statistically significant relationships between body weight and maximal oxygen intake. It was shown by Keys *et al.* (4) that semi-starvation results in a decrease of maximal oxygen intake which is proportional to the body weight until a weight loss of 10 per cent is reached. Somewhere between a 10 and a 17 per cent loss of weight, the decline of maximal oxygen intake is markedly increased and there is a substantial loss in the capacity for anaerobic work.

Body Composition and Maximal Oxygen Intake. The relationship of maximal oxygen intake to body composition has been previously investigated by von Döblen (9), Buskirk (3), Buskirk and Taylor (19), Welch *et al.* (22) and Dempsey (20).

Using 35 male and 35 female physical education students and staff ranging in age from 19 to 30 years, von Döblen determined body fat by water immersion densitometry (9). The maximal oxygen intake was directly determined from the nomogram provided by Astrand and Ryhming (23). He found there was not a linear relationship between total body weight and maximal oxygen intake. However, the results showed a correlation coefficient of $r = 0.75$ between the fat-free body weight and maximal oxygen intake. This relationship was

statistically significant at the .01 level of confidence. It was concluded that the fat-free body weight was the superior metabolic reference standard for the maximal oxygen intake.

Buskirk (3) and Buskirk and Taylor (19) carried out a similar study to that of von Döblen (9), using 46 healthy subjects who varied widely in terms of obesity and regular activity. The body composition measures were determined by the water immersion, densitometric technique and the maximal oxygen intake was determined by treadmill running. The correlation coefficients between maximal oxygen intake and a) fat-free body weight, b) active tissue and c) body weight were found to be 0.85, 0.91 and 0.63 respectively. Upon dividing the sedentary students into three groups according to their relative obesity, it was shown that there was no difference in maximal oxygen intake per kilogram of fat-free weight in the three groups. It was concluded that when maximal oxygen intake is used to examine the capacity to perform exhausting work the values should be expressed as oxygen per kilogram of body weight, but when the test is used to examine the performance of the respiratory-cardio-vascular system, the values should be expressed as oxygen per kilogram of fat-free weight. It was also concluded that physical conditioning effects the maximal oxygen intake independently of the mass of active tissue.

A similar relationship was studied by Welch <u>et al</u>. (22) on 28 healthy young men. They concluded that the circulatory

system appeared to be the major limiting factor in maximal oxygen consumption in as much as body weight, fat-free weight or fat-free weight minus bone weight accounted for only 35 per cent, 41 per cent and 41 per cent respectively, the variance in the maximal oxygen intake. The relative physical condition of the subjects was not reported in this study.

Maximal Oxygen Intake Tests. The maximal oxygen intake has been determined in a number of ways.

However, when a treadmill is used as the exercise device, the work intensity can only be increased by increasing the speed of running, or a combination of the two. Astrand (cited in 9), Robinson (7), and Hill (24) have increased the work intensity by increasing the speed of running. Wright (25), Knehr *et al.* (17), Keys *et al.* (4), Taylor, Buskirk and Henschel (13), Mitchell, Sproule and Chapman (14) and Cunningham (26) have increased the work load by increasing the grade for running. Buskirk (3) summarized and compared the results of some of these studies (7,9,24,25,17,4,13) and found that the mean values for the maximal oxygen intake expressed in cubic centimeters per kilogram of weight per minute were relatively constant with the exception of Astrand's (9) data. However, Astrand (cited in 9) used subjects in superior physical condition while the subjects in the other studies were relatively sedentary.

Hill and Lupton (cited in 27:927) found that the maximal oxygen intake varies from one individual to another and Taylor,

Buskirk and Henschel (13) reported that this maximal level varies for different work conditions.

The maximal oxygen intake was determined by Keys *et al.* (4) from a three-minute treadmill run at a speed of seven miles per hour with the grade varied according to the individual capacity of the subject. A warm-up walk at 3.5 miles per hour on a 10 per cent grade was performed prior to each test. The test consisted of several trials, which were two days apart, with an increase of 2.5 per cent in the treadmill grade on each trial. The trials were repeated until the oxygen intake was similar on two successive occasions. Expired air was collected from 1 minute and 45 seconds to 2 minutes and 45 seconds of the three-minute run, for purposes of calculating the oxygen intake.

A similar test to that of Keys *et al.* (4) was developed by Taylor, Buskirk and Henschel (13). This test began with the subjects in a post-absorptive state. A preliminary walk at 3.5 miles per hour at a 10 per cent grade was followed by a 5 minute rest. Following the rest, subjects ran for 3 minutes at 7 miles per hour on a grade previously selected on the basis of the score the subject received from the Harvard Fitness Test (28). Each subsequent run was at a grade 2.5 per cent higher than the previous run and was held on a separate day. If two successive determinations of oxygen intake differed by less than 150 c.c. per minute, it was considered that the maximal oxygen intake had been reached.

The test took from 3 to 5 days to administer.

These authors (13) made the following observations:

1. Using a constant speed and increasing the grade is more satisfactory than using a constant grade and varying the speed.
2. Oxygen intake apparently reached a steady state in the 3 minutes allotted.
3. An increase of 2.5 per cent in the grade was accompanied by an increase in oxygen consumption of approximately 300 c.c. per minute.
4. There was no apparent effect on the maximal oxygen intake from increasing the speed from 7 to 8 miles per hour.
5. Eating a light meal had no apparent effect on the maximal oxygen intake.
6. A warm-up prior to the test increased the maximal oxygen intake.

The reliability of this test ($r = 0.95$) was reported to be constant over a one-year period (13:80).

Slonim _et al_. (29) determined how well peak oxygen intake could be predicted from observations made at two levels of submaximal work. The test began with a 3.5 mile per hour warm-up at a 10 per cent grade for 6 minutes, followed by a 30 minute rest. The subjects then exercised at a constant speed of 3.5 miles per hour at grades of 20, 24 and 28 per cent for 6 minutes at each grade until the subject was unable to

complete the test. The grade was then decreased at 1 per cent intervals until a test was found which could be completed. The tests at the 20 and 24 per cent grades were performed on the same day. Thereafter, one test was performed each day.

The method employed by Mitchell, Sproule and Chapman (14) consisted of the following procedures:

1. The test began with a 10 minute warm-up at 3 miles per hour and at a 10 per cent grade.
2. A 10 minute rest followed the warm-up and each subsequent run.
3. The subject ran for 2.5 minutes at a zero per cent grade and expired air was collected during the last minute of the run in order to determine oxygen intake.
4. The grade was increased by 2.5 per cent for each subsequent run until the oxygen intake levelled off or the difference between two successive trials did not exceed 0.054 liters per minute.

The maximal oxygen intake test is considered to be free of motivation and emotion and is largely independent of skill (13:73). For this reason, it is the most satisfactory means for describing individual work capacity (30:680).

Heart Rate and Maximal Oxygen Intake. It has been shown by Karpovich (15), Wahlund (31) and Astrand (23) that pulse rate is roughly a linear function of oxygen consumption and work load. However, Wahlund (31) has further added that this linear relationship does not always exist at heavier work

loads. Berggren and Christensen (32) have shown that oxygen consumption and pulse rate are rectilinearly related.

At the work load which results in maximal oxygen intake, Asmussen and Nielsen (33), Christensen (cited in 11) and Mitchell, Sproule and Chapman (14) have reported maximal heart rates of 180, 170, and 187, $\pm$ 10 beats per minute respectively. Balke and Ware (30), Rushmer (34), Asmussen and Nielsen (33) and Wahlund (31) are in general agreement, that 180, $\pm$ 10 beats per minute is the maximum effective heart rate.

Body Composition. In order to arrive at an estimate for a desired mass of the body, certain quantities or components are individually estimated, the desired mass being calculated from these components. This section endeavors to define the compartments of the body and to review the methods of determination.

Keys and Brozek (35:246) believe that if a system of body analysis is required for the study of total energy metabolism, a distinction between the metabolically more active part of the body and the relatively inactive part of the body is required. "Among the latter will be listed, at once, the extra-cellular fluid, the bone mineral and the depot fat." (35:246). The need for such a distinction has led to the appraisal of body composition in terms of partitions or compartments.

At present, two possible approaches for arriving at an approximation of the metabolically active component of the body

are popular. One approach utilizes the principle of densitometry for the calculation of body fat to produce what is referred to as the fat-free body mass (35:264). The inclusion of an estimation of the extra-cellular fluid and an estimation of bone mineral produces what has been termed "active-tissue". The other approach is based on an estimation of total body water, an estimation of extra-cellular fluid and the assumption that the mass of cells in the body is hydrated at a constant level. This approach yields the so-called "cell-mass". The first approach was used in the present study to determine the total body fat and the fat-free body weight.

Lim and Luft (36:826) define the principles involved in the determination of body density and the estimation of body compartments:

1. that the sum of the fractions of the body mass is equal to unity and
2. that the total body volume is equal to the sum of the volumes of the compartments.

Behnke (37) and Behnke *et al*. (38) demonstrated the possibility of calculating the amount of body fat from the determined specific gravity of the entire body. The principle involved is that the density of human fat is much less than the density of the other body components. Therefore, the smaller the fat component of the body the larger the total body density. The body volume used for the calculation of body density is obtained from the principle of Archimedes. That is, the body

displaces its own volume of water when completely submerged and the difference between the weight of the body in air and the weight of the body in water is the weight of the displaced volume of water. This is actually an "apparent body volume" and must be corrected for the volume of air in the lungs, the respiratory passages and the gastro-intestinal tract.

In order to establish a method for measuring the proportion of the human body composed of fat, Rathbun and Pace (39:675) developed the equation:

$$\% \text{ Fat} = 100\left[\frac{5.48}{\text{sp.gr.}} - 5.044\right]$$

from data and assumptions provided by Behnke (37) and Behnke et al. (38) and from data provided by the animal studies of Pace and Rathbun (40) and Morales et al. (41). Thus an estimate of percentage body fat could be made from a measure of the specific gravity of the total body.

The concept of lean body mass was introduced by Behnke et al. in 1942 (38:495). This component was described as " ... a basic mass of lean tissue upon which varying amounts of excess body fat are superimposed." The study also defined excess fat as: " ... the storage or depot substance in fat cells." The lean body mass is considered to include a small fraction of essential lipoids in the nervous system and cell walls, but this tended to be a constant fraction. However, Keys and Brozek (35:369) experienced difficulty in actually defining the lean body mass because the "essential lipoids"

or amount of fat necessary for life cannot be measured. In place of the lean body mass, Keys and Brozek (35) developed the concept of the fat-free body mass.

The formula of Rathbun and Pace (39:675) and Behnke's concept of the lean body mass (38:495) are both based on the assumption that the lean mass has a constant density. This assumption was based on studies of tissue electolysis and body composition in animals and man. Murray (42:103) found that the chemical composition of the non-fatty material in animals was relatively constant. A similarity of the composition of the lean mass was evident for different animals after maturity. These findings were supported by Moulton (43:79), Pace and Rathbun (40:685) and Spray and Widowson (44:332). In the Rathbun and Pace (39:675) formula the density for body fat was calculated to be 0.94 (38:495) and the assumed density for the lean body was 1.100.

Forbes questioned the validity of the lean body mass concept by stating (45:484): "The fact that individual tissue samples show a high degree of constancy when composition is calculated on a fat-free basis, does not allow one to assume that the total lean body mass does not change as fat is added to or subtracted from the organism."

Fidanza _et al_. (46:254) calculated the average density of human fat to be 0.9007 gm./c.c. at 37°C. with no significant difference due to sex or bodily location of the fat. However, Keys and Brozek (35:276) found the average density of tissue

gained in 10 men by simple over-eating was found to be 0.9478 at 37°C. It was also noticed that there was a simultaneous increase in the extra-cellular fluid. The tissue gained was termed living obesity tissue and was composed of 62 per cent fat, 7 per cent cellular matter and 31 per cent extra-cellular fluid. These findings have been substantiated by Johnston and Berstein (47:45).

Ljunggren (48:24) introduced the terms "non-obesity tissue" and "obesity-tissue" as the body compartments. It was concluded, on the basis of small animal study, that the composition of two compartments was consistent in both normal and obese subjects, independent of sex (48:53).

In light of the findings of Fidanza (46), Keys and Brozek (35) corrected the first major mistake made by failing to observe that water density changes with temperature. These workers were also dissatisfied with the underlying assumption that the fat-free body had a fixed density. Beacause this density is not precisely knowable and may not actually exist as a constant, Keys and Brozek (35) took a new approach to the problem.

The new approach visualized the body of a reference man defined as a 25 year old individual whose relative body weight was 100 according to the standard tables used in the United States. The density of this reference body was obtained from the data of Brozek (51) on 25 healthy men and calculated to be 1.0629 gm./c.c. (51:786). Any change from this reference body was assumed to involve changes in cellular matter, fat and

hydration (35:277). The assumption was made that the reference body contains 14 per cent fat. This approach enables one to express the relative fatness of an individual with respect to this reference man. The amount of fat in a given body can be approximated, as a fraction of body weight by the following formula (35:280):

$$f = \frac{4.201}{D} - 3.813$$

<u>Further Considerations of Body Density</u>. In order to eliminate the effect of the variable amount of air in the lungs, the apparent body weight under water must be corrected for the residual air in the lungs and respiratory passages. That is, the weight of the water displaced by the residual air must be subtracted from the apparent weight of the body under water in order to give a true body volume.

The formula for body density, as presented by Keys and Brozek (35:268), then becomes:

$$Db = \frac{Ma}{\frac{Ma-Mw}{Dw} - Vr}$$

where:

Db = body density

Ma = mass in air

Mw = apparent weight in water

Dw = density of water

Vr = weight of water replaced by residual air.

This formula is applicable to measurements taken with the subject at maximal expiration.

The residual volume can be measured by either a closed or open circuit spirometer system. The first is the closed-circuit method where hydrogen, nitrogen or helium is added to the air in a spirometer of a known volume. The initial concentration of gas in the air of the spirometer is recorded and the subject re-breathes through the system until the foreign gas concentration is at complete equilibrium in the lungs and the spirometer.

Some investigators have either assumed absolute values or calculated percentages of the vital capacity for prediction of the residual lung volume (50:19). However, it was reported by Keys and Brozek (35:273), that assuming an average value for the volume of residual air results in a standard deviation of $\pm$ 4 per cent body fat. These authors investigated the accuracy of the direct method of lung volume determination and reported a resultant error of only $\pm$ 0.8 per cent body fat.

It has been speculated that total body immersion in water will have a compressive effect on the volume of air in the lungs (51:243). Brozek et al. (51) compared "submerged" and "land" residual volume measurements twice within one week on 9 healthy males. The results indicated that the values obtained for "submerged" lung volumes were, smaller, on the average, by only 118 c.c. The use of land - determined residual volumes would lower the estimated fat content of the body by less than on per cent.

The lung volume one should attempt to achieve at the

moment of underwater weighing is still an uncertain point. According to Carlsen and Chen (cited in 52:99) as long as the lung volume is measured it makes essentially no difference what volume of air remains in the lungs at the moment the under water weight is observed. On the other hand, Welch and Crisp have found (53) that lower body densities result with the subject at one-half vital capacity than at maximal expiration. The explanation of these investigators was that the fuller lung is more susceptible to compression from the hydrostatic pressure. Buskirk (52:99) believes this concept is reasonable if one considers the absolute, and not relative, change in a small as compared to a large volume when exposed to an external pressure.

Howell, *et al*. (54:402) reported greater reproducability of results by weighing the subjects under water at maximal inspiration. The statistical reliability reported was r = 0.84.

One of the volumes not accounted for by the usual under water weighing procedures is the volume of gas in the gastro-intestinal tract (V.G.I.). Buskirk (52:100) reviews numerous studies which have attempted to measure the V.G.I. but most of these methods failed to produce acceptable results. It is suggested that perhaps the best values for V.G.I. were obtained using a total body plethysmographic technique and an intra-gastric balloon. This method was used by Bedell *et al*.(55,56) who found an average V.G.I. of 115 ml. in a large series of patients and normal subjects. However, the reported range was

from 0-500 ml. among subjects and 50-300 ml. from day to day in the same subject. On the basis of these findings, Buskirk proposed (52:101) that this value be incorporated into the calculation of body density as a correction value.

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CHAPTER III

METHODS AND PROCEDURE

The subjects were 30 volunteer males associated as students or staff at the University of Alberta during the month of June, 1963. They were selected on the basis of the availability of the subjects and the length of period the subjects had been training. The co-operation of all subjects was gained through personal contact by the writer. The subjects were all training for, or competing in, a sport of their specialty at the interscholastic or the professional level, with the exception of four individuals who were classified as "active". All subjects participated in a minimum of one hour of vigorous training or competition for a minimum of four days per week and had been carrying out such a program for at least one month.

All necessary determinations on a given subject were performed within the span of one week, including the test and re-test procedures on all measures. The determinations included:

1. Maximal oxygen intake test.
2. Hydrostatic weighing for body density.
3. Total lung volume determinations.

Maximal Oxygen Intake Test. The maximal oxygen intake test has been described by Mitchell, Sproule and Chapman (1) and, with some modification, by Cunningham (2). The test was performed on a Quinton Motor Driven Treadmill, Model 18-49-B with a speed range of 0 to 9 miles per hour. Each subject was briefed as to the exact procedures to be followed and as to the

purpose of each portion of the test.

The following procedures were used:

1. A ten-minute warm-up walk was performed at 3 miles per hour and at a ten per cent grade.
2. A rest of ten minutes in the supine position was taken after the warm-up.
3. Following the rest period the subject was allowed to breathe quietly with a nose-clip in place, through a rubber mouthpiece into an Otis-McKerrow 2-way breathing valve connected by 1.5" rubber tubing to a 150 liter Douglas Bag. A 3-way #p-321 Thomas valve was placed at the junction of the airway leading from the mouthpiece into the Douglas Bag.
4. The exercise runs were carried out at a speed of 8 miles per hour for 2.5 minutes, using the breathing valve apparatus, supported by an adjustable headgear suitably designed so that it would not restrict the subject while running on the treadmill (see Figure 4).
5. The first exercise run was carried out at a zero per cent grade. The expired air was collected in the 150 liter Douglas Bag between 1 minute and 30 seconds and 2 minutes and 30 seconds of the run. The oxygen intake was then determined.
6. After a 10 to 15 minute rest, the treadmill grade was increased by 2.5 per cent each subsequent run, with a constant speed of 8 miles per hour, and the procedure

was repeated until the oxygen intake, measured in liters per minute, levelled off or declined. The criteria for deciding whether or not maximal intake had been reached, if the intake did not decline, has been determined, by Mitchell, Sproule an Chapman (1:539), to be a difference of less than .054 liters between two successive tests.

Method of Determining Oxygen Consumption. The expired air in the Douglas Bag was analyzed for the percentage of oxygen by drawing a sample of expired air through the exit tubing of the bag via a ¼" vinyl hose into a Beckman #E-2 oxygen analyzer. The percentage of carbon dioxide was determined by the same procedure, using a #KK Godart Capnograph infra-red carbon dioxide analyzer. Both gas analyzers were carefully calibrated prior to use each day and at regular intervals during the testing procedure. The volume of expired air was determined by passing the contents of the bag via a 1.5" rubber hose leading from the 3-way Thomas valve through an #802 American Meter Company Gasometer at a constant rate of 70 liters per minute with a Collins #p-553, 1/15 horse power centrifugal pump. The total volume was corrected for temperature and pressure, to standard temperature and pressure dry from the factors given in tables supplied by Warren E. Collins Inc. (3:27).

For the calculation of oxygen consumption, the change in nitrogen content for correction of expired to inspired volumes, as described by Peters and Van Slyke (4), was employed. The

method of calculation is shown below:

1. The following symbols are used for this study:

   a) Fe = % of a particular gas in expired air.

   b) Fi = % of a particular gas in inspired air.

   c) Ve = Volume expired.

   d) Vi = Volume inspired.

   e) ATPS = Atmospheric temperature, pressure, saturated.

   f) STPD = Standard temperature, pressure, dry.

2. The corrected volume of air expired is:

   Ve air STPD = Ve ATPS x the factor for reducing a volume of moist gas to a volume of dry gas at $0^{o}C$. and 760 m.m. of mercury.

3. The corrected per cent of oxygen in the expired air is:

   $$Fe\ O_2 = \text{Analyzer reading} \times \frac{2.5}{1000}$$

4. The volume of inspired air is:

   $$Vi \text{ air STPD} = Ve \text{ air STPD} \times \frac{Fe\ N_2}{Fi\ N_2} \qquad (Fi\ N_2 = 79.04)$$

5. The total volume of oxygen inspired (not all consumed) is:

   $$Vi\ O_2 = Vi \text{ air} \times \frac{Fi\ O_2}{100} \qquad (Fi\ O_2 = 20.93)$$

6. The volume of oxygen expired (not consumed) is:

   $$Ve\ O_2 = \frac{Fe\ O_2}{100} \times Ve \text{ air}$$

7. The amount of oxygen consumed is:

   $$VO_2 = Vi\ O_2 - Ve\ O_2$$

Heart Rates. The heart rates were recorded on one occasion only for each subject during the maximal oxygen intake test.

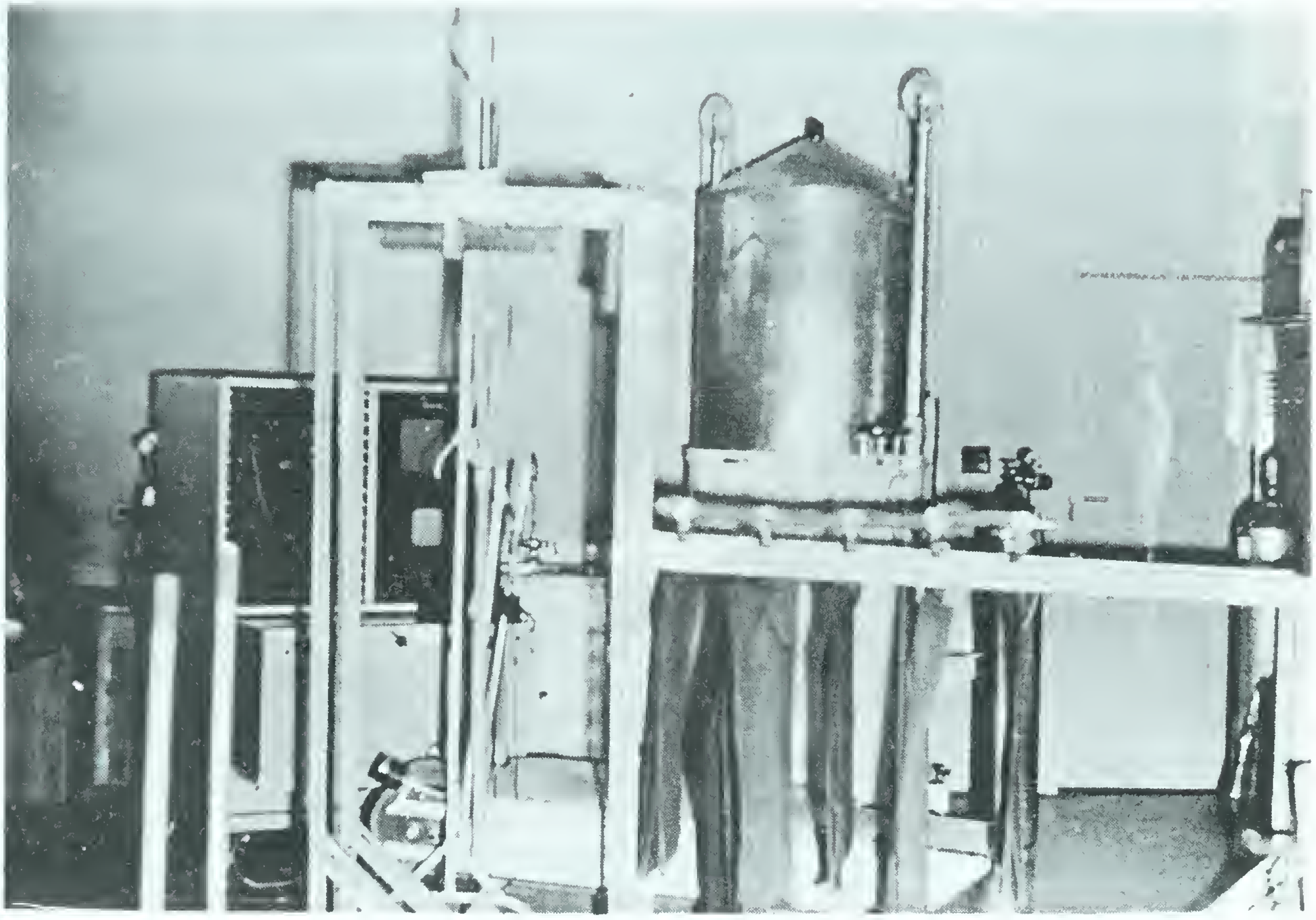

FIGURE 1. APPARATUS – Treadmill, Douglas Bags, Gasometer and Electrocardiograph

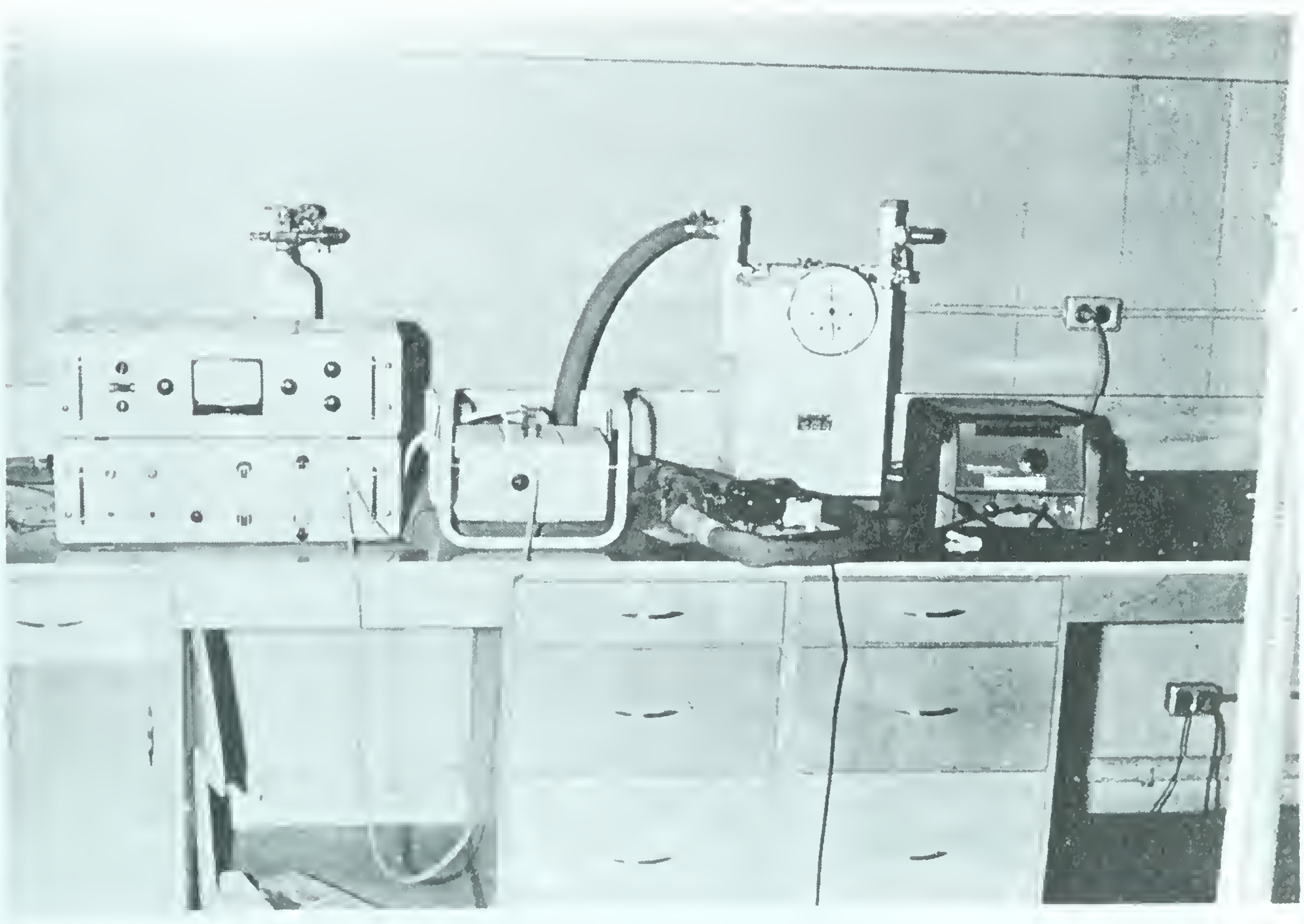

FIGURE 2. APPARATUS – Oxygenanalyzer, Carbon Dioxide Analyzer and Volume Gasometer

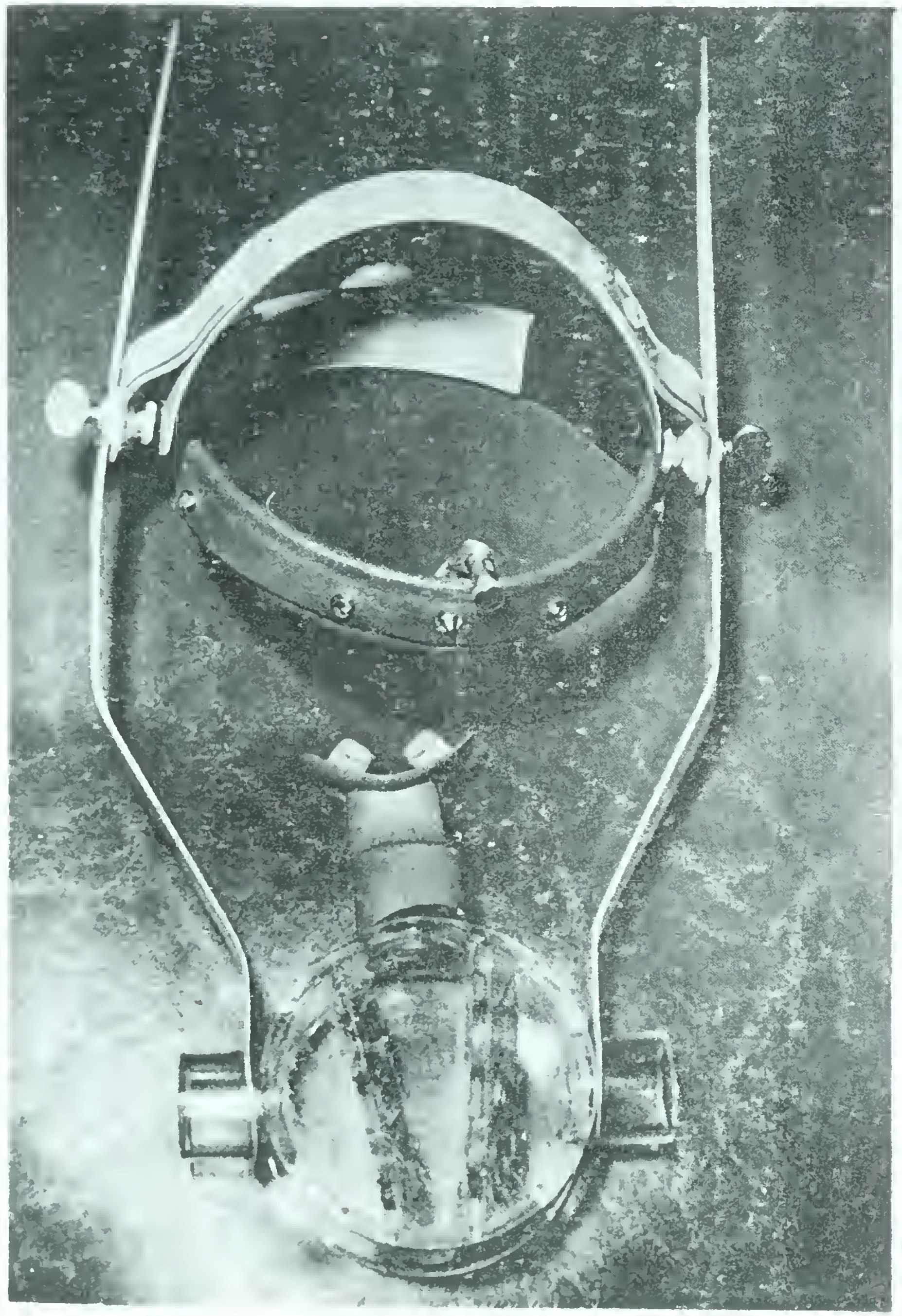

FIGURE 3 HEAD GEAR with MODIFIED
OTIS McKERROW VALVE

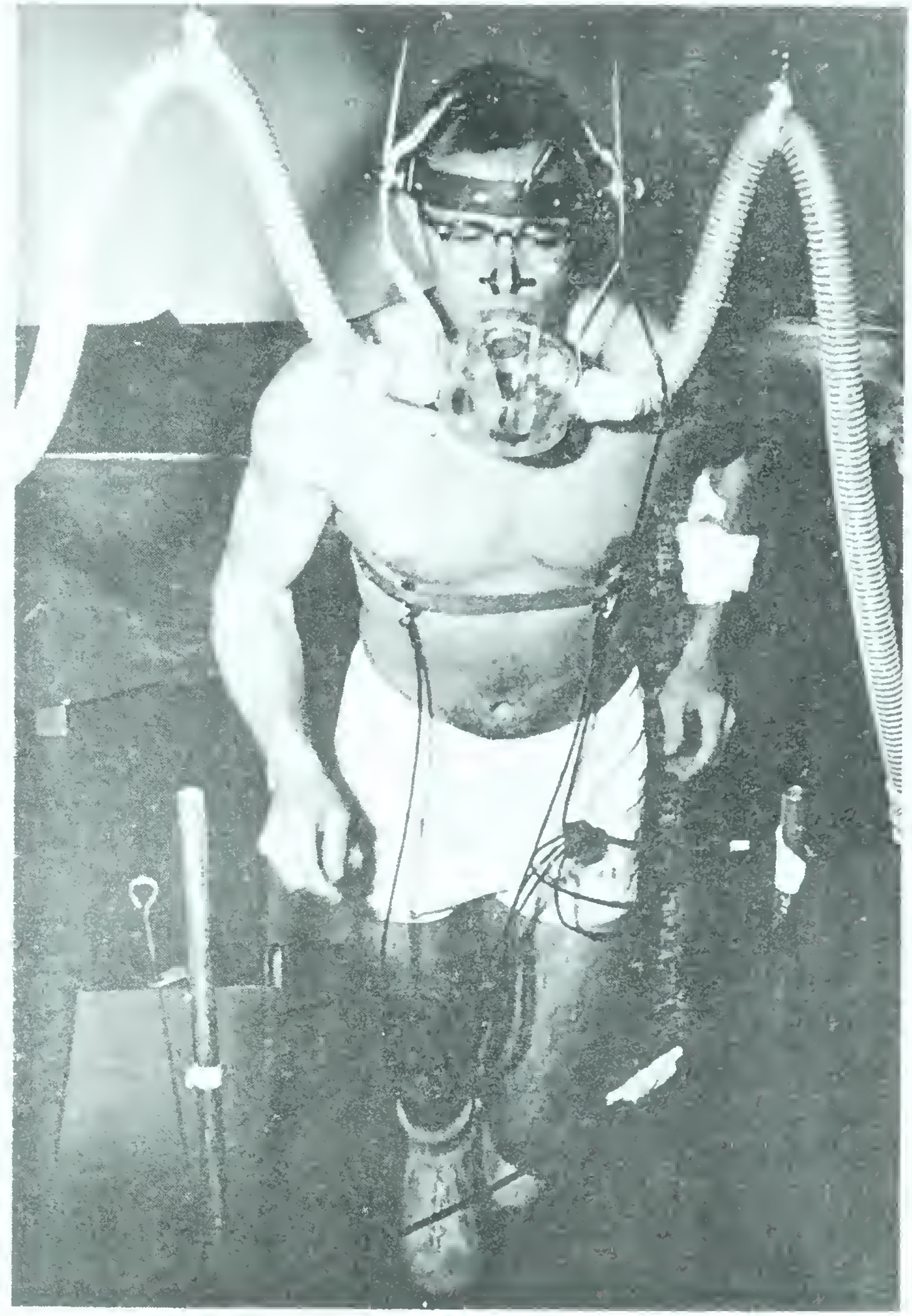

FIGURE 4 MAXIMAL PERFORMANCE TRIAL
Showing Overhead Suspension

An Electronics for Medicine Incorporated, 8 channel Electrocardiograph with a photographic "Rapid Writer" provided a permanent record of the subject's heart rate. Two electrode plates were positioned by means of an elasticized band on the chest, immediately below the nipples. A third electrode plate was grounded to the forehead by means of the headgear. Redux electrode paste was used to reduce skin resistance. This procedure provided a clear deflection with a minimum of artifacts during the running. During each run of the Maximal Oxygen Intake Test, the heart rate was recorded for 5 seconds at 1 minute and 30 seconds, 2 minutes and 2 minutes and 30 seconds of the run.

<u>Densitometric Determination of Body Compartments</u>. Total body fat was computed from body density by the equation of Keys and Brozek (5:280):

$$F = (4.201/D) - 3.813$$

Body density was determined by the Archimedean principle using water immersion densitometry as outlined by Keys and Brozek (5) and as used with some modification by Dempsey (6). The following details outline the procedure as used in this study:

1. <u>Hydrostatic Weighing Technique</u>. The weighing took place in the diving area of the University swimming pool during hours when the pool was not in use to ensure the calmest conditions possible. The measurement apparatus consisted of the following:

a) Toledo "No Springs" Scale (Model No. 15594) which was suspended from the one metre diving board.

The scale was graduated in ounces and the dash pot was filled with number 20 oil to dampen the scale hand movement and provide more accurate readings.

b) A weighted abdominal belt which ensured negative buoyancy for all subjects, was attached, by cables, to a circular metal apparatus which served to keep the cables away from the subject's body, and this apparatus was hooked to the bottom of the scale.

The apparent submerged weight was determined as follows:

a) The weighted belt was secured around the abdomen and the subject quietly entered the pool holding on to the edge.

b) The subject submerged and scrubbed the body to remove gas bubbles in the skin and hair.

c) Immediately following a maximal inspiration, the subject was lowered into the water until he was totally submerged. Special care was taken to prevent unnecessary disturbance of the water so the reading could be taken without delay.

d) When the subject had reached a position of full extension (the abdominal belt was 18 inches below water surface), with the arms hanging in contact with the body, and the scale hand settled, the reading was taken to the nearest ounce. This

Figure 5 HYDROSTATIC WEIGHING APPARATUS

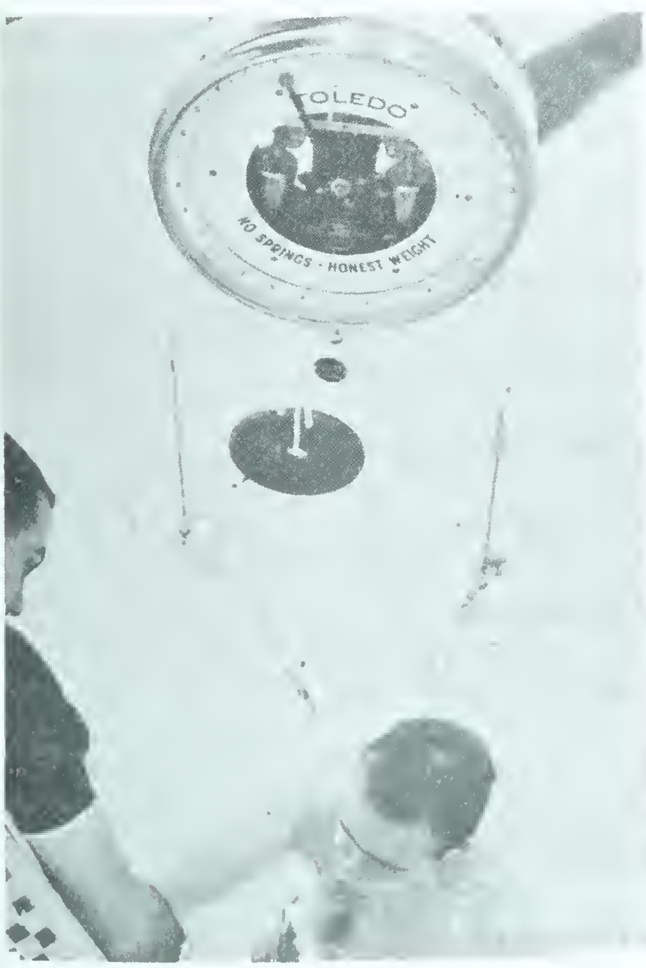

Figure 6 SUBMERSION (Maximal inspiration)

Figure 7 SUBMERGED POSITION (Maximal inspiration)

procedure was usually completed within 6-8 seconds.

e) Following the reading, the subject was touched on the chest with a pole and pulled to the surface.

f) The test was repeated until the lowest measured weight was obtained ($\pm$ 2 ounces) on three trials. Each subject was given three to five training trials to help overcome the fear of submersion and to promote relaxation during the test. The room and water temperatures and barometric pressure were recorded at the time of each weighing.

2. Formula for Body Density.

a) Body Density =

$$\frac{\text{Weight in Air}}{\text{Weight in air} - \text{weight in water} - 0.0362\ (\text{T.L.C.}-\text{V.G.I.})}$$

X Density of Water

b) The total lung capacity (T.L.C.), in cubic inches was converted to pounds by multiplying by 0.0362.

c) The density of water was corrected for water temperature.

d) The volume of gas in the gastro-intestinal tract (V.G.I.) was assumed to be 115 ml. which is an average proposed by Bedell *et al.* (7:664) from plethsymographic determinations.

e) A sample calculation sheet for body density and the body compartments appears in the appendix.

<u>Measurement of Total Lung Volumes</u>. The total lung capacity was determined on land by the closed circuit, helium dilution technique. Procedures and calculations were based on the principle as outlined by Comroe <u>et al</u>. (8: 15-17), (see Appendix B). The measurements were taken on a Godart Pulmotest and Pulmo-anlysor, type 44A-2 and recorded at the 60m.m. per second speed of the three speed kymograph.

The subject, in the sitting position, re-breathed quietly, with a nose-clip in place, through a rubber mouthpiece connected to a 'Y' valve which was connected by a 1.5" rubber hosing to a spirometer of a known volume, containing a known concentration of helium. The calculation of the residual volume of air in the lungs (that portion which cannot be expired) was determined from the measured functional residual volume (Residual volume = functional residual volume - expiratory reserve volume). A constant flow of oxygen, from a second spirometer, to the first spirometer, was maintained to insure that the subject never re-breathed expired gas.

Vital capacity measurements were conducted immediately following attainment of helium equilibrium, in the spirometer and the lungs, and the values were taken directly from the kymograph recording and corrected to B.T.P.S.

<u>Measurement of Total Body Weight</u>. Total body weight was taken on a standard laboratory scale to the nearest quarter of a pound. Subjects were dry, in bathing suits, and were weighed immediatley following the hydrostatic procedures.

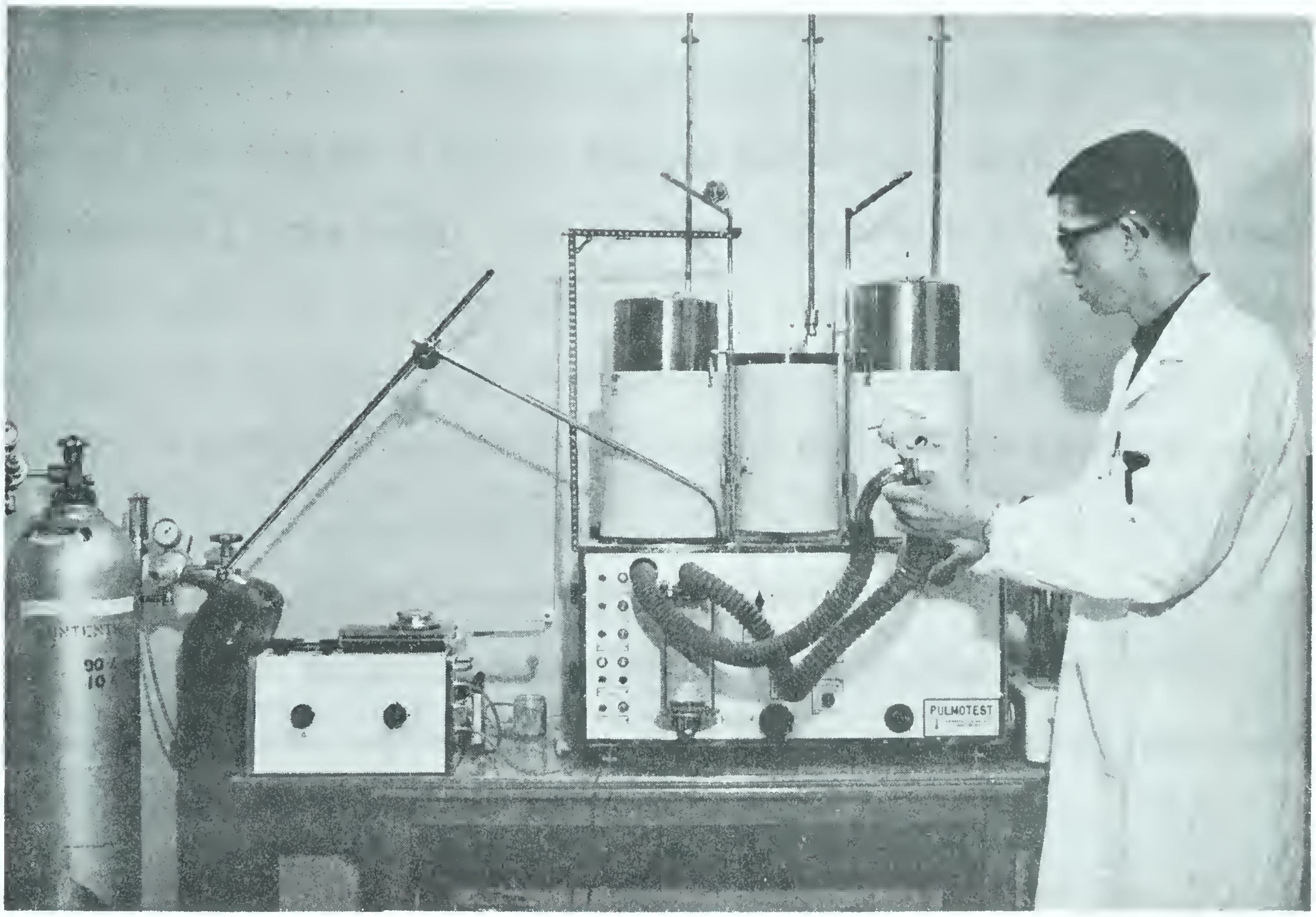

Figure 8 GODART PULMOTEST and PULMO–ANALYSOR TYPE 44 A–2

<u>Test-retest Reliability</u>. Test-retest reliability was studied on 26 subjects for maximal oxygen intake, 26 subjects for apparent submerged weight and 22 subjects for total lung capacity. In order to determine the reliability of the measurements, the Pearson Product-Moment method was used (9:143).

<u>Statistical Treatment</u>. In order to determine the statistical relationship of the variables under study, an inter-correlation matrix for all variables was constructed with the use of the I.B.M. - 1620 Electronic Computer. The program used, Number 1620-002 (10), also provided a mean and standard deviation for each variable. The inter-correlation matrix was then used as the basis for computation of a multiple regression equation between maximal oxygen intake and the total body weight, fat-free body weight, total body fat and maximal heart rates. The equation was calculated by the "Stepwise Procedure for Multiple Regression" as described by Efroymson (11). The procedure requires that at each successive "step" in the formation of the equation, the variable which accounts for the largest proportion of the remaining variation in the dependent variable is added. The $\underline{t}$ ratio of N-n-1 degrees of freedom (N = sample size, n = number of variables) provided a test to determine if the beta coefficients computed for each variable was significantly different from zero. The standard error of estimate of the predicted from the actual values were also determined for each successive regression equation.

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CHAPTER IV

RESULTS AND DISCUSSION

Results

Reliability of Measurements. The Pearson Product-Moment method (1:143) was used to determine the test-retest reliability coefficients for all measurements used. The reliability coefficients appear in Table I. Each of these reliability coefficients was statistically significant above the .01 level of confidence (for 26 subjects, $r \geq 0.487$ and for 22 subjects, $r \geq 0.515$).

TABLE I

Test-Retest Reliability Coefficients

Variable	Number of Subjects	Reliability Coefficient	Standard Error of Estimate
Total Body Weight (lbs.)	26	0.985*	1.865
Apparent Submerged Weight (lbs.)	26	0.929*	0.442
Total Lung Volume (Liters)	22	0.988*	0.114
Maximal Oxygen Intake (Liters/min.)	26	0.926*	0.174

*statistically significant above the .01 level of confidence.

The duplicate determination of total lung volumes on 22 subjects resulted in a reliability coefficient of 0.988 with a standard error of estimate of 114 c.c. which proved to be the highest reliability for all measures. A reliability coefficient

of 0.926 was determined for maximal oxygen intake, with a standard error of estimate of 174 c.c., which was the lowest reliability calculated.

Observations on Subjects. The data for observations made in the 30 subjects of this study are summarized in Table II and presented in detail in Appendix C.

The subjects were in the age range of 19 to 34 years, with a mean age of 23.1 years, ± 4.3. The mean total body weight, fat-free body weight and total body fat were 75.05, ± 7.2 kilograms, 72.08, ± 6.6 kilograms, and 2.97 ± 2.7 kilograms, respectively. The mean maximal oxygen intake was 4.75 liters per minute with a standard deviation of 0.699 liters.

TABLE II

Means, Standard Deviations and Ranges of

Observations Made on 30 Active Males

	Age (yrs.)	Total Body Wt. (kgs.)	Fat-free Body Wt. (kgs.)	Total Body Fat (kgs.)	Max. VO_2 (L/min.)
Mean	23.1	75.05	72.08	2.97	4.75
Standard Deviation	4.3	7.2	6.6	2.7	.699
Range	19-34	59.5-88.1	58.2-83.1	0.0-12.4	3.13-6.28

Correlation Analysis. An analysis was made of the relation of maximal oxygen intake to total body weight, fat-free body weight, total body fat and maximal heart rate. The triangular intercorrelation matrix computed from the five measurements taken on the 30 subjects is presented in Table III.

Total body weight correlated 0.926 with the fat-free body weight which was statistically significant above the .01 level of confidence. The correlation coefficient obtained for the relationship of total body weight to total body fat was 0.422, and of total body weight to maximal heart rate was 0.424, both of which were statistically significant at the .05 level of confidence.

TABLE III

Intercorrelation Matrix Between Body Measurements, Heart Rate and Maximal Oxygen Intake N = 30

Variables	Total Body Weight	Fat-Free Body Wt.	Total Body Fat	Maximal Heart-Rate	Maximal O_2Intake
Total Body Weight	———	0.926*	0.422**	0.424**	0.262
Fat-Free Body Weight		———	0.049	0.363**	0.397**
Total Body Fat			———	0.251	-0.264
Maximal Heart Rate				———	0.136
Maximal Oxygen Intake					———

* $r \geq 0.463$; Statistically significant above the .01 level of confidence

** $r \geq 0.361$; Statistically significant above the .05 level of confidence

The fat-free body weight also correlated significantly at the .05 level of confidence with maximal heart rate and with maximal oxygen intake, yielding coefficients of 0.363 and 0.397, respectively. The fat-free body weight was the only measure to correlate significantly, above the .05 level of confidence, with maximal oxygen intake. Therefore, the null hypothesis was rejected and the alternate hypothesis accepted with respect to the relationship of the fat-free body weight to the maximal oxygen intake. However, the null hypothesis was not rejected with respect to the relationship of total body weight, total body fat and maximal heart rate to maximal oxygen intake. In the latter relationships, the correlation coefficients were not statistically significant at the .05 level of confidence.

Regression Analysis. A summary of the regression line data, as derived from the intercorrelation matrix, is presented in Table IV. The correlation coefficient between maximal oxygen intake and fat-free body weight was 0.397 and the resultant regression equation was:

$$\text{Max. } VO_2 = 1.694 + 0.0424 \ \text{(Fat-free Wt.)};$$

where 1.694 is the intercept on the Y axis (ay) and 0.0424 is the slope of the regression line (by). The variation around this regression line as indicated by the standard error of estimate (sy.x) was 641 c.c. of oxygen per minute.

The total body weight related to the maximal oxygen intake resulted in a correlation coefficient of 0.262 and the regression equation was:

$$\text{Max. } VO_2 = 2.874 + 0.025 \text{ (Total body weight)},$$

with a standard error of estimate of 674 c.c. of oxygen per minute.

TABLE IV

The Relationship of Maximal Oxygen Intake to Body Weight, Fat-Free Body Weight, Total Body-Fat and Maximal Heart-Rate.

N = 30

	Body Wt. (kg.)	Fat-Free Wt.(kg.)	Total Fat (kg.)	Maximal Heart-Rate (beats/min.)
r	0.262	0.397	-0.264	0.136
ay	2.874	1.694	4.95	2.81
by	0.025	.0424	-0.0679	0.0109
Sy.x	0.674	0.641	0.674	0.219

The relationship of total body fat to maximal oxygen intake yielded a correlation coefficient of -0.264 and a regression equation of:

$$\text{Max. } VO_2 = 4.95 + (-0.0679) \text{ total body fat},$$

with a standard error of estimate of 674 c.c. of oxygen per minute.

The correlation coefficient between maximal heart rate and maximal oxygen intake was 0.136 and the regression equation which resulted was:

$$\text{Max. } VO_2 = 2.81 + 0.0109 \text{ (maximal heart rate)}.$$

The calculated standard error of estimate for this regression line was 219 c.c. of oxygen per minute.

Regression lines and their respective standard errors of estimate relating the maximal oxygen intake in liters per minute to fat-free body weight, total body weight, total body fat and maximal heart rate were plotted in Figures 9,10,11, and 12 respectively, from the computed regression equations. The data plotted in Figures 9 to 12 show the distribution of the subjects about the regression line and one standard error of estimate. The plotted regression lines further illustrate the low correlations obtained in this study.

Multiple Regression Analysis. The "Stepwise Procedure for Multiple Regression", as described by Efroymson (8), was used to determine the relative size of the contribution of each variable to the criterion (maximal oxygen intake). The results of this analysis appear in Table V. The variables were ranked according to the order of their inclusion in the final multiple regression equation. The second column in Table V shows the percentage of interpersonal variance in maximal oxygen intake accounted for by the inclusion of each variable into the multiple regression equation. The *t* scores, which tested the significance of the beta coefficients for each regression, and the standard error of estimate, which indicates the deviation between the actual and the predicted values of maximal oxygen intake for each regression equation, are also presented.

The single variable which contributed the most to the variance of maximal oxygen intake was the fat-free body

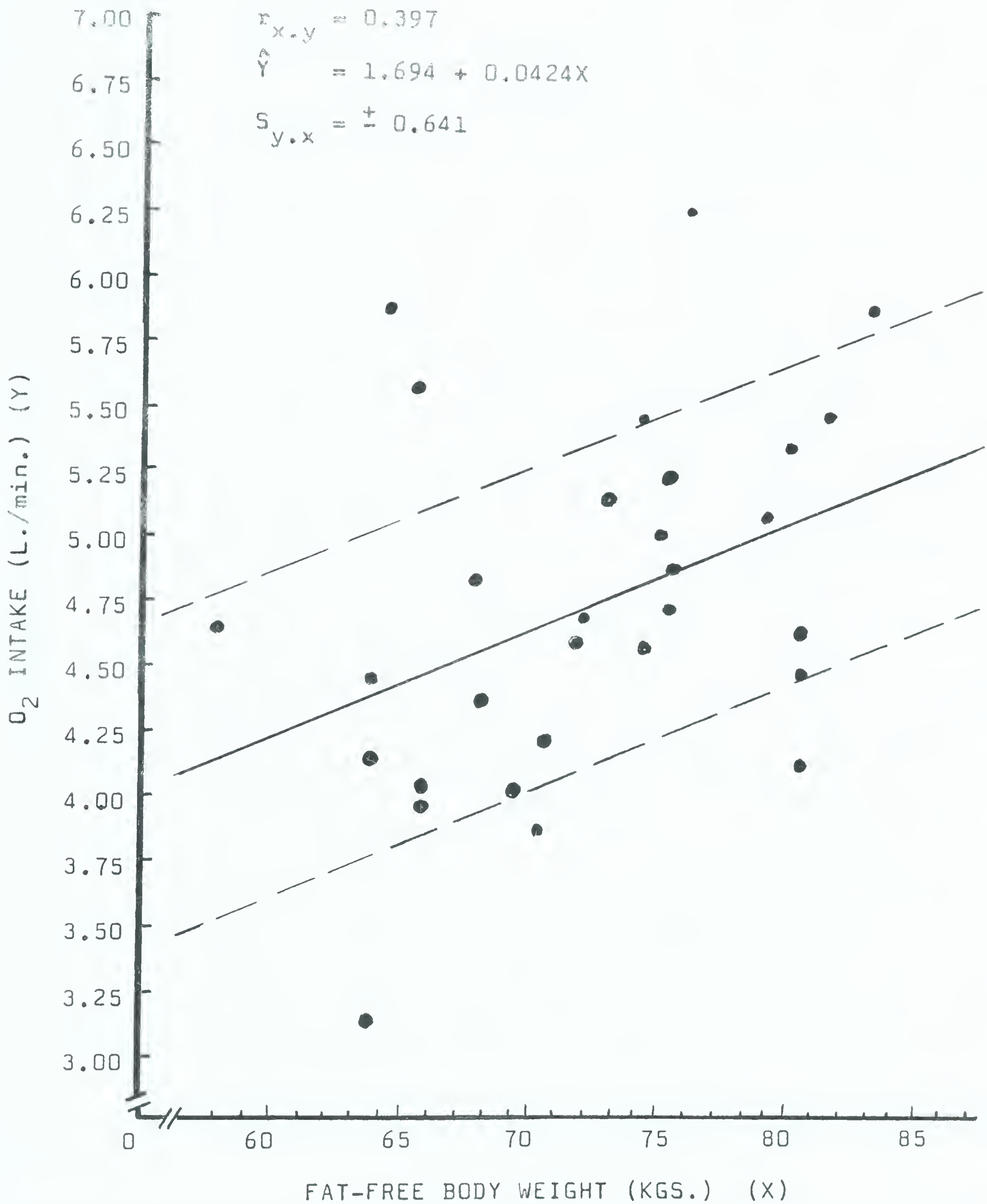


FIGURE 9 THE RELATIONSHIP BETWEEN FAT-FREE BODY WEIGHT AND MAX. VO_2.

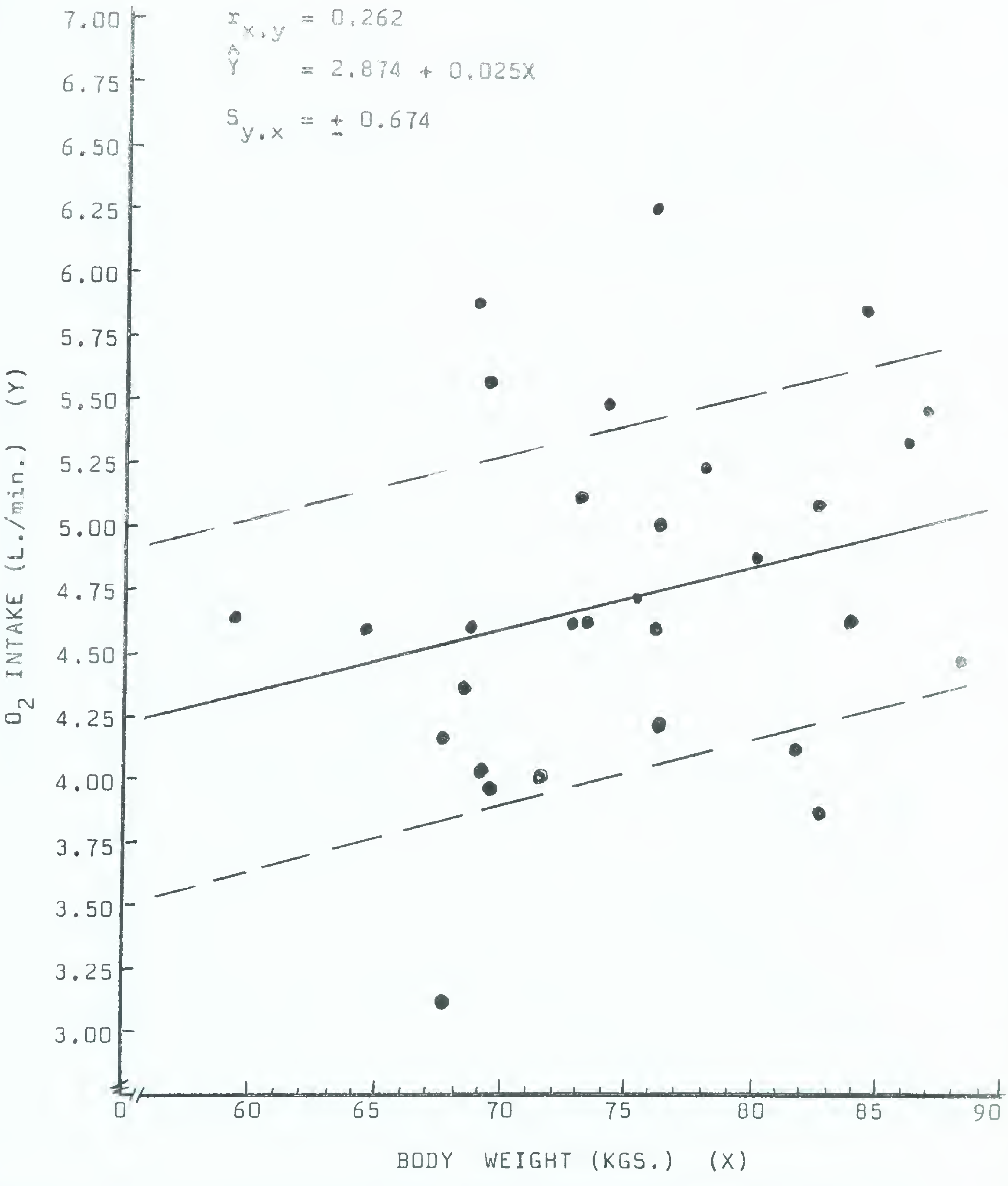


FIGURE 10 THE RELATIONSHIP BETWEEN TOTAL BODY WEIGHT AND MAX. VO_2.

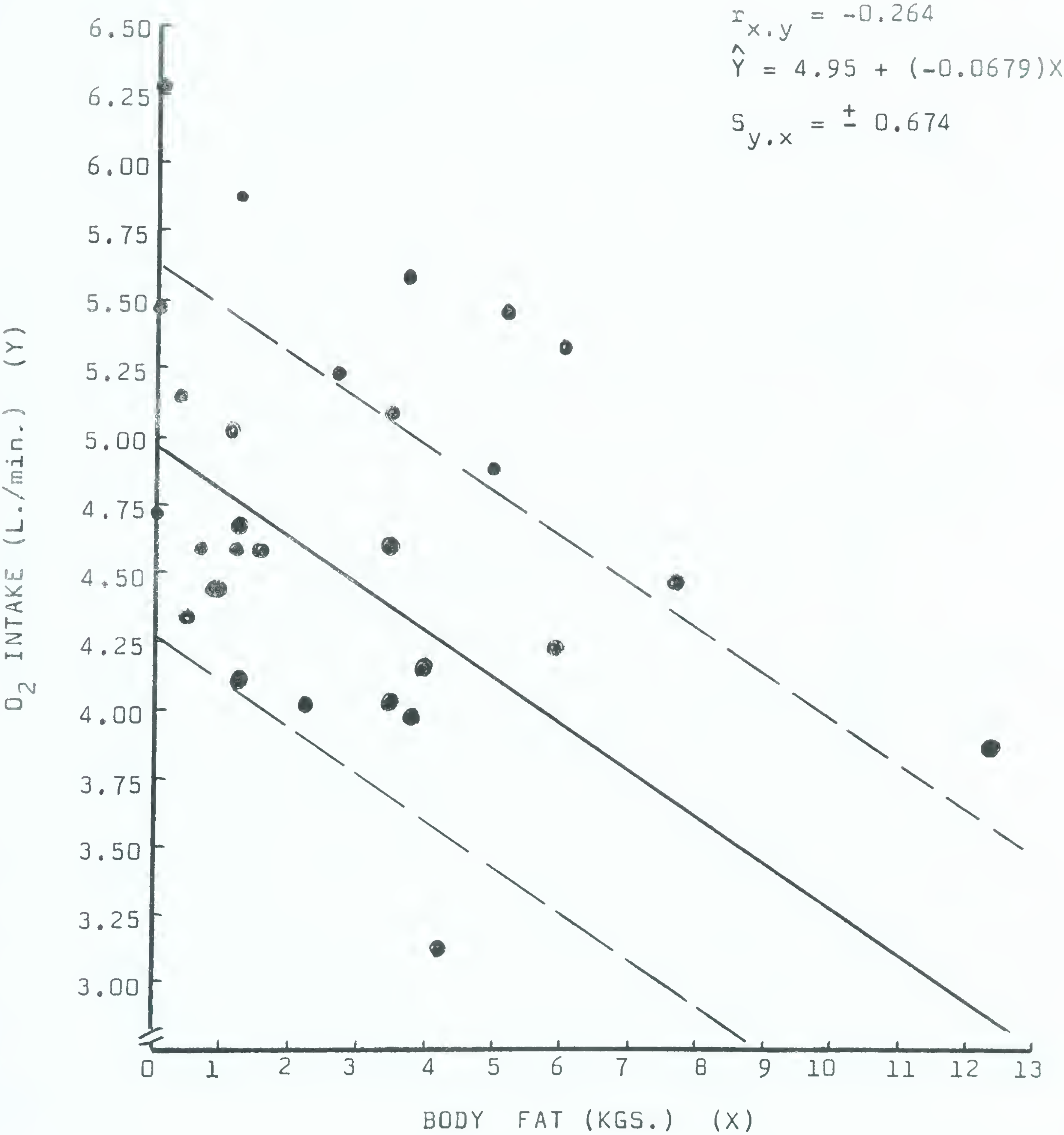


FIGURE 11 THE RELATIONSHIP BETWEEN TOTAL BODY FAT AND MAX. VO_2.

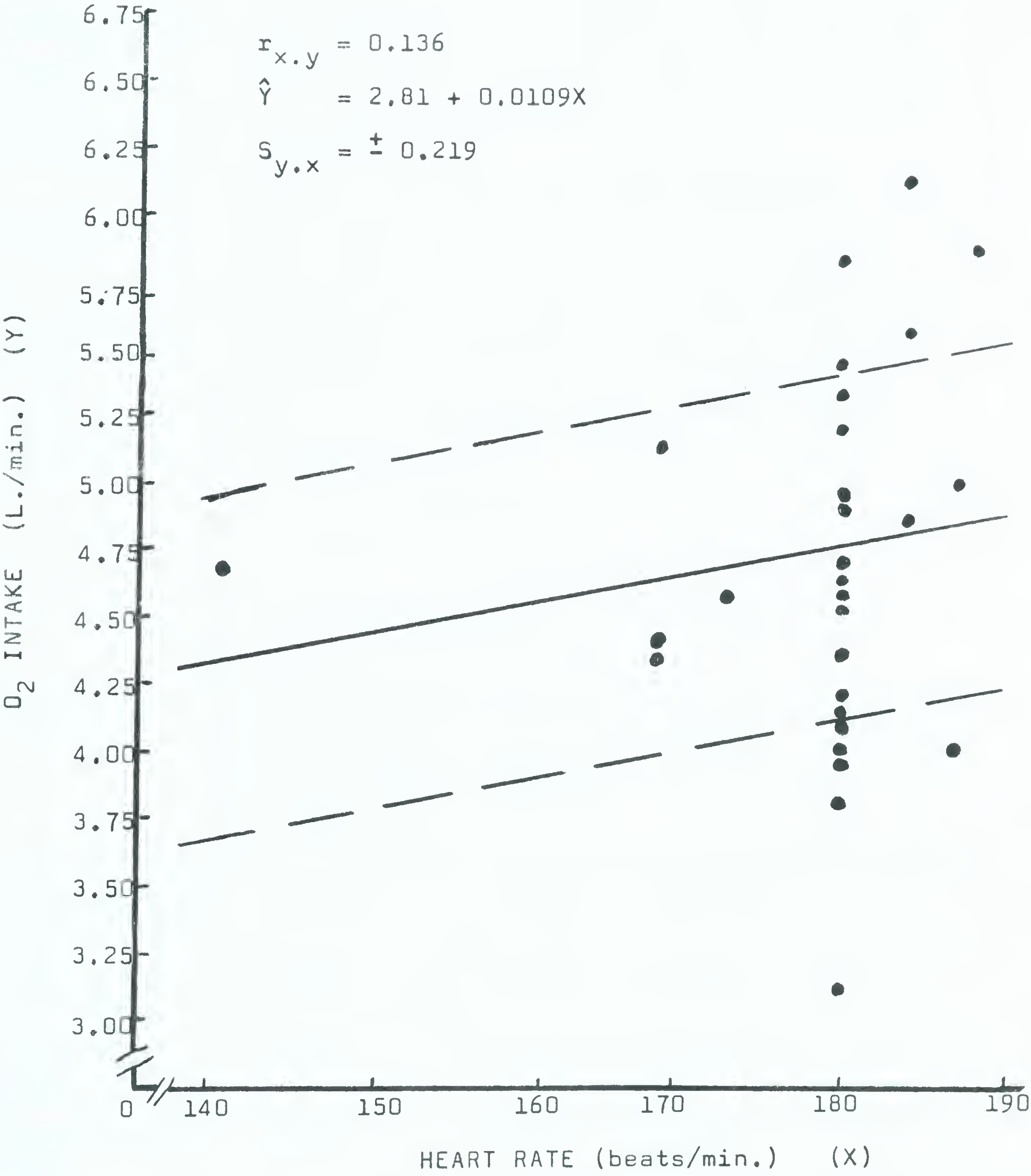


FIGURE 12 THE RELATIONSHIP BETWEEN HEART RATE REACHED AT MAX. VO_2 AND MAX. VO_2.

weight. This variable accounted for 15.76 per cent of the total interpersonal variance in the maximal oxygen intake and yielded a beta coefficient with a t value of 2.89 which was statistically significant above the .05 level of confidence for 28 degrees of freedom.

The inclusion of total body fat, total body weight and maximal heart rate into the regression equation accounted for an additional 8.06 per cent, 4.35 per cent and 0.37 per cent, respectively, of the total variance. However, the beta coefficients computed for each of these variables was not statistically significant.

TABLE V

Relationship Between Maximal Oxygen Intake and Various Body Measurements and Heart Rate (Multiple Regression Analysis) N = 30

Variable	Percentage of Total Variance Accounted for by regression (%)	Standard Error of Estimate (L/min.)	t score Beta Coefficient	Rank
Fat-free Body Weight (Kgs.)	15.76	0.653	2.289**	1
Total Body Fat (Kgs.)	8.06	0.633	1.690	2
Total Body Weight (Kgs.)	4.35	0.626	1.255	3
Maximal Heart Rate	0.37	0.637	0.363	4

Total variance accounted for 28.54 %.

**Statistically significant at the .05 level of confidence degrees of freedom = N-n-1 = 28.

The total variance accounted for by all four variables was 28.54 per cent and the variance accounted for by the three measures of body mass and body composition, omitting maximal heart rate, was 28.17 per cent. However, it must be remembered that the only statistically significant contribution was made by the fat-free body weight. Therefore, as a metabolic reference unit to maximal oxygen intake, the fat-free body weight was the most useful measure tested in the present study. However, in terms of practical prediction with the regression equation, its uses would be very limited because it only accounts for 15.76 per cent of the total variance of the criterion, the maximal oxygen intake, as calculated on the 30 active males in this study. The other equations were not considered useful because the beta coefficients were not statistically significant from zero.

The multiple correlation coefficient for fat-free body weight and total body fat to maximal oxygen intake was 0.488 with an F ratio value of 4.224 which was statistically significant at the .05 level of confidence. When total body weight was added to the multiple correlation, the coefficient became 0.531 with an F ratio value of 3.401 which was also statistically significant at the .05 level of confidence. When the variable of maximal heart rate was added to the multiple correlation, the coefficient became 0.534. This was not statistically significant at the .05 level of confidence which was understandable in view of the small percentage

(0.37%) contribution maximal heart rate made to the total variance. Therefore, in terms of prediction, a more reliable estimation of the maximal oxygen intake could be calculated with the inclusion of the three measures of body mass and body composition, fat-free body weight, total body fat and total body weight. However, in terms of practical prediction, this combination would also be very limited because it only accounts for 28.17 per cent of the total variance, which leaves unaccounted for, another 71.83 per cent.

<u>Heart Rate and Maximal Oxygen Intake.</u> The mean maximal heart rate reached on the treadmill run which produced the maximal oxygen intake was 178 beats per minute. Figure 13 shows the relationship of mean heart rates to mean oxygen intake (in some cases, this was the zero per cent grade), c) the grade at which maximal oxygen intake was reached and d) the grade immediately following the attainment of maximal oxygen intake. The mean heart rates in beats per minute were 161.3, $\pm$ 9.10; 171.4, $\pm$ 6.44; 178.6, $\pm$ 5.2 and 179.6, $\pm$ 4.5 compared to mean oxygen intakes in liters per minute of 3.90, $\pm$ 0.448; 4.33, $\pm$ 0.633; 4.83, $\pm$ 0.608 and 4.28, $\pm$ 0.748. The number of subjects used for these determinations was 27 because 3 individuals reached their maximal oxygen intake at the zero per cent grade. Figure 13 illustrates a trend for heart rate and oxygen intake to increase curvilinearly until the maximal oxygen intake is attained, at which time, the heart rate continued to rise slightly while the oxygen intake

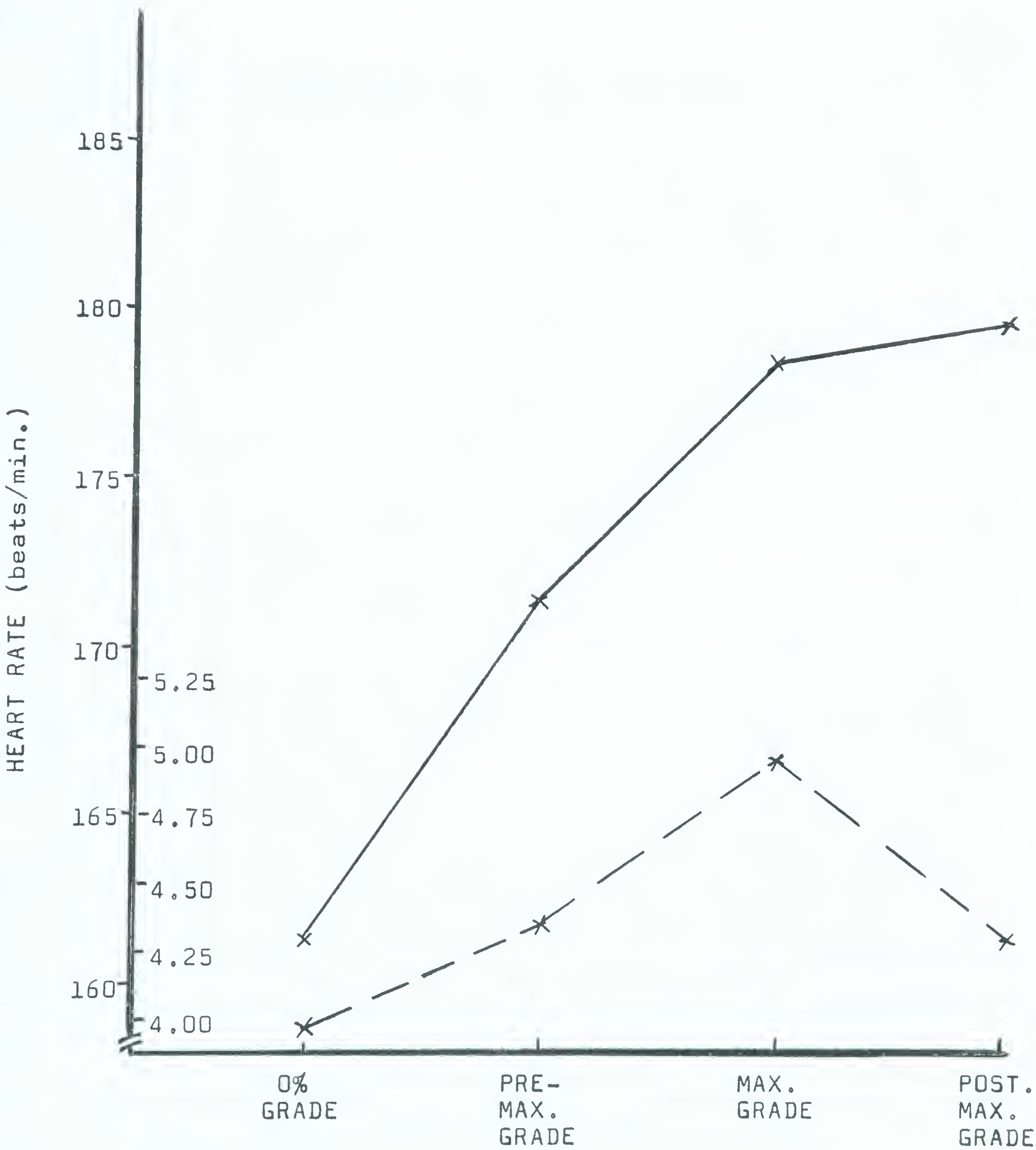
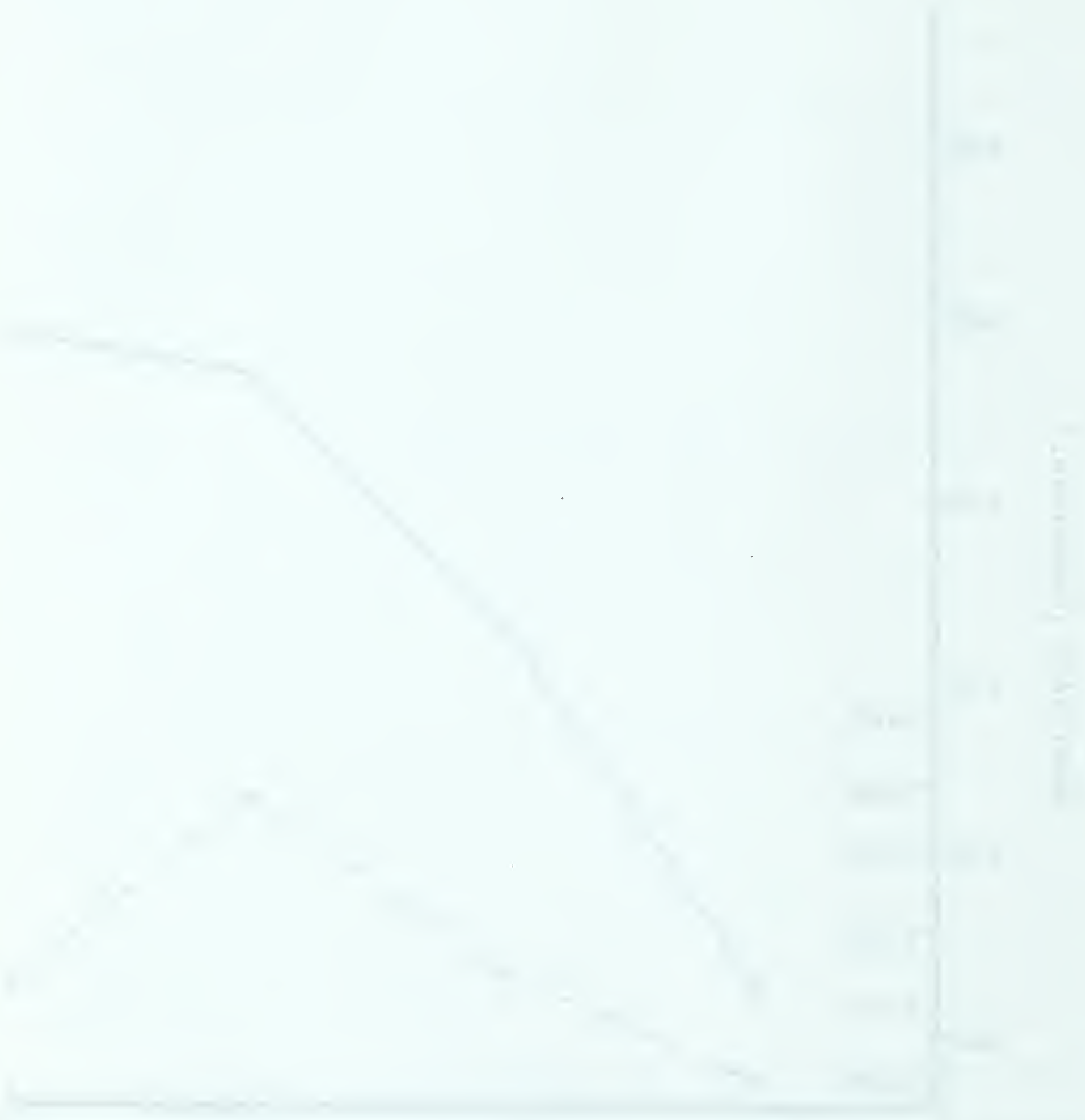


FIGURE 13 MEAN HEART RATE AND O_2 INTAKE AT ZERO GRADE, AT ONE GRADE BELOW MAX. VO_2, AT MAX. VO_2 AND AT ONE GRADE ABOVE MAX. VO_2.



declined.

Discussion.

Reliability of Measurements. The reliability coefficient for the maximal oxygen intake test was found to be high (r = 0.926) for the 26 subjects used in this study. Keys *et al.* (3), using a similar test, performed a test-retest on a total of 15 subjects, determining the oxygen intake at two different levels, the higher grade being 2.5 per cent greater than the lower. The largest differences between mean values of oxygen consumption were found to be 50 c.c. which were considered not important by the experimenters. No reliability coefficient was stated.

In 1944, Taylor (4) reported a reliability coefficient of 0.70. However, the running time, sampling time and working conditions varied within the test and were different again from that used in this study.

Buskirk (5:50) reported a reliability coefficient of 0.98 with a standard error of estimate of 86 c.c. of oxygen for the same maximal oxygen intake test as used by Keys *et al.*(3). Taylor *et al.* (6:77) determined the coefficient of reliability for 28 suplicate determinations to be 0.95 on the same test. The standard error of estimate was 84 c.c. of oxygen. The major differences between the test used by Buskirk (5), Taylor *et al.* (6) and Keys *et al.* (4) and the test used in the present study were: a) the test took 3 to 5 different days to administer, whereas in the present study, a test was completed

within 3 hours on a single day; b) a preliminary test was given all subjects to determine the necessary work load to produce a maximal oxygen intake, whereas in the present study, all subjects started at the same work load; and c) the environment and physiological variables were very closely controlled, whereas in this study, such factors as temperature, pressure, time of day and time of test after meals, were not controlled.

Duplicate trials on 15 normal men to determine the repeatability of the maximal oxygen intake test were carried out by Mitchell, Sproule and Chapman (7). From the raw data provided by these authors (7:540), the Pearson Product-Moment reliability coefficient (1:143) was calculated and found to be 0.917 with a standard error of estimate of 132 c.c. of oxygen. These authors also indicated that almost all the variance could be attributed to interindividual differences (7:541). The latter test and the test in the present study were essentially the same, except for the treadmill speed which was 6 miles per hour and 8 miles per hour respectively. The repeatability, therefore, of the maximal oxygen intake test used in this study, was found to be highly reliable ($r = 0.926$) and quite comparable to the values reported by other authors (3,4,5,6,7,) who have investigated this technique.

The reliability coefficients for total body weight ($r = 0.985$) and for apparent weight under water ($r = 0.929$) were highly significant and comparable to values reported by other authors (8.9.10).

In the present study, the reliability coefficient of 0.929 for apparent submerged weight was slightly lower than that obtained by Dempsey who used the same method and obtained a reliability coefficient of 0.983 (10:84). The hydrostatic weighing technique in both studies, was carried out with the subject submerged following a maximal inspiration and the total lung capacity was not measured at the time of weighing. The two major differences which may have accounted for the differences in reliability coefficients were: a) Dempsey's work (10) all measurements were performed with subjects in a post-absorptive state in an attempt to eliminate variances in the volume of gas in the gastro-intestinal tract, whereas, in the present study this factor was not controlled; and b) in Dempsey's work (10) the test retest procedures were performed on accomplished swimmers who were accustomed to submersion, whereas, in this study, many of the subjects were non-swimmers or beginning swimmers which may have resulted in lower degrees of consistency with reference to breath-holding under water.

The reliability of total body weight was 0.985 which is considered very high for most measures but is still slightly lower than the coefficient of reliability of 0.999 reported by Dempsey (10:84). However, the difference could probably be explained by the fact that in this study, test-retest procedures were not carried out on consecutive days in a post-absorptive state. The time between tests varied from one to four days.

Total lung volumes as determined on land by the helium dilution technique (11) proved to be very reliable (r = 0.988) in test-retest procedures. The major contributing factors to this high reliability may have been due to the fact that both determinations were carried out on the same day, with approximately 20 minutes between tests. This procedure was considered acceptable by Behnke (19) and it was adequate to measure net body volume with an error not exceeding the range of 0.004 density units.

Comparative Observations. Table VI shows comparisons of data gained from this study with those from similar studies. All the studies dealt with similar age groups, which ranged from 19 to 34 years. The range of means for total body weight was 65.8 to 78.6 kilograms and the range of means for per cent body fat was 3.9 to 15.9 per cent. The range of means for maximal oxygen intake in liters per minute was from 3.37 to 4.75. From Table VI, the following pertinent observations, regarding this study, may be stated:

a) The mean maximal oxygen intake of 4.75, ± 0.699 liters per minute is the highest reported mean for all six studies summarized. The two studies which report the second and third highest means are those of Buskirk (5) and Astrand (12) respectively, both of whom studied highly trained athletes. Although it is difficult to compare directly the results of two similar studies with reference to maximal oxygen intake, these observations seem to verify the assumption that the

TABLE VI

COMPARISON OF OBSERVATIONS ON BODY COMPOSITION MEASURES AND MAXIMAL OXYGEN INTAKE WITH OTHER STUDIES

Investigator	N	$\bar{X}$ Age (yrs)	$\bar{X}$ Total BodyWt. (kgs)	$\bar{X}$ Fat-free Wt. (kgs)	$\bar{X}$ % Fat	$\bar{X}$ Total Fat (kgs)	$\bar{X}$ Max. VO_2 (L/min)	$\bar{X}$ Max. VO_2 (cc/kg wt/min)	$\bar{X}$ Max. VO_2 (cc/kg fat-free wt/min)	Type Subject
Coyne	30	23.1 $\pm$4.3	75.05 $\pm$7.2	72.08 $\pm$6.6	3.9 $\pm$3.2	2.97 $\pm$2.7	4.75 $\pm$0.699	63.54 $\pm$9.67	65.89 $\pm$10.59	active
Buskirk (5)	39	22.5 $\pm$2.8	78.6 $\pm$16.9	66.11	15.9 $\pm$7.8	12.5	3.4 $\pm$0.46	44.6 $\pm$5.5	53.1 $\pm$3.4	sed.
Buskirk (5)	15	21.7 $\pm$2.7	75.8 $\pm$13.5	69.8	7.87 $\pm$6.6	5.96	3.95 $\pm$0.43	52.8 $\pm$5.5	57.5 $\pm$ 3.4	mod. active
Buskirk (5)	5	20.2 $\pm$1.3	65.8 $\pm$5.0	60.75	7.87 $\pm$0.76	5.05	4.32 $\pm$0.35	65.8 $\pm$3.4	71.2 $\pm$3.4	Cross-Country runners
von Döblen (13)	35	26.1	69.3 $\pm$1.4	61.8	10.6	7.35	3.91 $\pm$0.09	56.4	63.2	P.E. maj. & Staff
Welch *et al.* (14)	28	23.7 $\pm$1.9	75.3 $\pm$9.6	64.0	15.1 $\pm$5.8	11.8 $\pm$5.8	3.73 $\pm$0.45	49.5	58.3	not rep.
Mitchell *et al.* (7)	36	20-29	75.4				3.37 $\pm$0.51	44.7 $\pm$3.9		sed.
Astrand (12)	42	20-30	70.4 $\pm$1.0				4.11 $\pm$0.06	58.6 $\pm$0.7		well trained

subjects pf this study were "active".

b) When the maximal oxygen intake was expressed in cubic centimeters per kilogram of body weight per minute, or in cubic centimeters per kilogram of fat-free body weight per minute, the subjects of this study ranked second only to the five cross-country runners studied by Buskirk (5). The respective values were 63.54 $\pm$ 9.67 c.c./kg. wt./min. and 65.89 $\pm$ 10.69 c.c./kg. fat-free wt./min. for this study and 65.8 $\pm$ 3.4 c.c. /kg. wt./min. and 71.2 $\pm$ 3.4 c.c./kg. fat-free wt./min. for Buskirk's subjects (5).

Comparison of Correlations. The correlation coefficients obtained for the relationship of the measures of body composition and total body weight to maximal oxygen intake in this study were compared to correlation coefficients obtained in other studies. The comparison is illustrated in Table VII. It was noted in Table VI that the studies compared used subjects of similar age groups, but differing in degree of regular activity. The maximal oxygen intake was determined by treadmill running in all studies with the exception of von Döblen (13) who estimated the maximal oxygen intake from a nomogram provided by Astrand (12).

The correlation coefficients for total body weight to maximal oxygen intake found by the present study, Welch et al. (14), and Buskirk (5) were: 0.262, 0.59 and 0.63 respectively. The latter two were statistically significant above the .01 level of confidence but the coefficient of correlation for

this study (r = 0.262) was not statistically significant.

All four investigations studied the relationship of the fat-free body weight to maximal oxygen intake and in all cases, with the exception of Buskirk (5), found that this relationship yielded the highest coefficient of correlation as compared to other measures. The correlation coefficients determined from the present study, and those by Welch et al. (14), Buskirk (5) and von Döblen (13) were: 0.397, 0.65, 0.85 and 0.75 respectively. The coefficient of 0.397, in this study, was statistically significant at the .05 level of confidence while the coefficients of correlation from the other studies were statistically significant at the .01 level of confidence.

Buskirk (5) found the highest relationship to exist between "active tissue" and maximal oxygen intake (r = 0.91) but also found that the difference between this correlation coefficient and that obtained for the fat-free body weight and maximal oxygen intake (r = 0.85) was not significant. That is, the correlation coefficients for the two measures of body composition ("active tissue" and fat-free body weight) with maximal oxygen intake, were essentially the same.

Although it was not expressed as a correlation coefficient, Buskirk (5), Buskirk and Taylor (15) and Welch et al. (14) agree on the statement, that the maximal oxygen consumption was not significantly influenced by the percentage of body weight composed of fat. This study supports this concept as was evident from the statistically significant correlation

coefficient of -0.264 between total body fat and maximal oxygen intake.

TABLE VII

Comparison of Correlation Coefficients of Maximal Oxygen Intake to Measures of Body Composition and Total Body Weight in Similar Studies.

Max. VO_2 to	Correlation Coefficients			
	Coyne	Welch *et al.* (14)	Buskirk (5) Buskirk & Taylor (15)	von Döblen (13)
Total Body Wt. (kgs.)	0.262	0.59*	0.63*	
Fat-Free Body Wt. (kgs.)	0.397**	0.65*	0.85*	0.75*
Lean Body Mass (kgs.)		0.64*		
"Active Tissue" (kgs.)			0.91*	
Total Body Fat (kgs.)	-0.264			

* Statistically significant above the .01 level of confidence.

** Statistically significant above the .05 level of confidence.

<u>Measurement of Body Composition</u>. Only 13 of the 30 subjects in this study possessed more than 4 per cent body fat as determined by densitometric analysis and from the formula provided by Keys and Brozek (16:280). Three of the subjects possessed zero per cent fat. This latter finding, in reality, is an impossibility as it is well known that a certain amount

of lipid material, such as that present in the myelin sheath of nervous tissue, is essential for normal body functioning (5,16,17,18,20). It is therefore apparent from this and from the subjective evaluation that none of the subjects appeared emaciated, that the calculation of per cent body fat, and consequently total body fat from the formula of Keys and Brozek (16:280) has misrepresented the actual fat content of these individuals and possibly of many of the subjects who have very low percentages of body fat. However, it is also possible that the values obtained for some of these cases, fall within the errors of measurement and that the true values have been misrepresented. The former possibility cannot be disregarded in view of the limitation placed on the formula by the authors themselves (16:280). The formula was based on nutritional weight changes and was considered useful for a range of relative obesity from 10 per cent to 25 per cent and where gain or loss of weight involved a mass of relatively fixed composition. Therefore, the validity of the formula is based on the assumption that all changes in body density are a result of increases or decreases in obesity tissue. This may not be the case in athletes, some of whom are overweight because of muscle rather than fat (5,10,21,22). It was proposed by Buskirk (5:86) that some athletes may deposit tissue that is greater than 30 per cent cellular matter and maintain their original obesity tissue level. This would result in a higher density value, which would be interpreted

wrongly by the formula as a decrease in obesity tissue.

This concept has been previously discussed by Buskirk (5), Yuhasz (9) and Dempsey (10). Buskirk also pointed out that use of the equation provided by Rathbun and Pace (23) resulted in lower estimations of body fat than did the formula employed in the present study. Thus Keys and Brozek (16) made an improvement with respect to this particular point.

Body Composition and Maximal Oxygen Intake. The combination of three measures of body mass and body composition was found to account for 28.17 per cent of the total interpersonal variance in the absolute maximal oxygen intake. The fat-free body weight accounted for 15.76 per cent of this total variance. This relationship was also found (at the .01 level of confidence) by von Döblen (13), Buskirk (5), Buskirk and Taylor (15), and Dempsey (24). Welch *et al.* (14) also found a significant relationship between the fat-free body weight and maximal oxygen intake, but they also found that total body weight, which correlated significantly at the .01 level of confidence, was nearly as good an index for prediction. Upon comparing the relationship found in this study, which used active males, with the findings of other studies (5,13, 15,24), which used sedentary males as subjects, it is evident that the degree of relationship is considerably lower in the present study (0.39) compared to correlations ranging from 0.65 to 0.85). This low relationship is consistent with the findings of Buskirk (5), Buskirk and Taylor (15) and Dempsey (24)

who studied, in addition to the sedentary males, a small number of active males.

It has been shown by a number of investigators (5,12, 28A,29,31) that individuals taking part in regular physical conditioning programs have higher maximal oxygen intakes than do sedentary subjects. This was supported by the present study which shows a mean maximal oxygen intake, in liters per minute, which was the highest reported mean in the literature (4.75 liters per minute). With regard to maximal oxygen intake - expressed in cubic centimeters per kilogram of body weight or fat-free body weight - the results of this study are exceeded only by those of the Buskirk study (5), in which the subjects were five highly trained, cross-country runners. It was suggested by Taylor (32:148), that the difference between the sedentary individual and the physically active individual is in part due to an improved cardiovascular performance.

Under basal (13,16,25,26,27) and submaximal (28) conditions, the fat-free body weight has been found to be the superior metabolic reference standard as it offers the closest approximation to the metabolically "active tissue". The amount of oxygen used reflects the demands of the metabolically active tissues (5,13,32). However, during maximal work, the metabolic demands of the active tissues increase to such an extent that the amount of oxygen used is dependent upon the ability of the cardiovascular respiratory supply system to

adapt to the stress and meet the added demands. Therefore, the findings in basal and submaximal conditions cannot be extended into the maximal performance tests.

It should be pointed out, when relating two physiological variables by a reference standard that the one which gives the simplest, clearest and most general expression for this relation is theoretically the best. However, the accuracy of calculation or prediction is not the only criterion for the physiological value of a reference standard. It must also be physiologically meaningful. An illustration of this is provided from a study by Wedgewood _et al_. (34) who reported a correlation coefficient of 0.80 between interstitial fluid and basal metabolic rate. While this fluid compartment, statistically, accounted for 64 per cent of the variation in the basal metabolic rate. Brozek and Grande (35:27) have shown that its actual participation in the body's oxygen consumption must be practically zero. Therefore, use of interstitial fluid as a reference standard would be physiologically meaningless. The reference standard, therefore, must be a convenient means of prediction and must also provide the basis for the physiological interpretation of the limitations one variable has on the other.

Gross body measurements are often used to express metabolic reference standards. It has been shown (5,15,13, 14,28,32) that the maximal oxygen intake per kilogram of body weight is a good measure of the oxidative energy available

for moving a man from place to place. However, Kleiber (33) stated that the use of any gross body measurement is superfluous when one wishes to distinguish between metabolically "active" and (relatively) "non-active" tissue. It is well known that individuals of the same body build and size may differ considerably in body composition, particularly in total body fat.

It is clear, therefore, that in theory, if one is interested in evaluating the performance of the cardiovascular-respiratory system and in comparing one individual to another, the ideal reference unit would be the amount of "active tissue" performing the work. Evidence in support of this has been found by: Buskirk (5), Buskirk and Taylor (15), von Döblen (13) Welch et al. (14) and Dempsey (24) by reporting high and statistically significant correlation coefficients between the fat-free body weight and the maximal oxygen intake. In this case, the fat-free body weight allows a close approximation of the more metabolically active elements of the body. This has been found to a limited degree in the present study, because of the significant though low correlation between the fat-free body weight and oxygen intake.

Further support of the thesis that the maximal oxygen intake is dependent upon the amount of "active-tissue", of which muscle forms a great part during exercise, was first explored by Christensen (cited in 32) who found that a man doing work with his arms only had a lower maximal oxygen

intake than when he was working at full capacity on a bicycle ergometer. It was also shown by Christensen and Hogberg (30) and by Buskirk (5) that the addition of arm work, to already heavy work, increased the maximal oxygen intake.

Therefore, the use of the fat-free body weight as a reference standard appears to be justified on both the basis of high statistical relationship as well as the provision of a distinguishing basis for physiological interpretation. Moreover, the present study substantiates the role of physical "fitness" as an important determinant of an individual's maximal oxygen intake. Thus a unit of muscle in good condition and with increased "tone" would appear to have a potential for utilizing more oxygen per unit of time than flacid muscular tissue and this difference would be presumably initiated by adjustments in cardiac output, pulse rate, stroke-volume and arteriovenous oxygen difference.

In view of the above findings and discussion, a word of caution regarding the interpretation of such results seems warranted. The significant correlation coefficients found in other studies and to a lesser degree, in the present study, do not necessarily prove a casual relationship between the fat-free body weight and the maximal oxygen intake. Furthermore, it does not indicate that the cardio-vascular variables are unimportant as limiting factors, rather that the two variables are intimately related and, as Taylor adds (32:148) raises the question of whether one (the cardio-vascular variables) is

not influenced through some intermediate mechanism by the other (muscle mass). It was suggested by Buskirk (5:89) that possibly factors related to the cardiovascular respiratory supply system, together with a measure of muscle mass, would improve the units of reference. It is also possible that a more valid measure of the metabolically "active tissue" during exercise, would result in an improved reference standard.

Heart Rate and Maximal Oxygen Intake. The mean heart rate reached in conjunction with the maximal oxygen intake was 178.6, ± 5.2 beats per minute. This finding was consistent with that of Asmussen and Nielsen (36), Christensen (cited in 32) and Mitchell, Sproule and Chapman (7). It has been reported by Karpovich (37:84), Wahlund (38) and Astrand (12) that pulse rate is roughly a linear function of oxygen consumption and of work load. Berggren and Christensen (39) have shown that oxygen consumption and pulse rate are rectilinearly related. It is generally agreed (36,37,38, 39,40) that the maximal effective heart rate is approximately 180 beats per minute. It was explained by Rushmer (40:440) that at faster heart rates the ventricular filling period is decreased and the stroke volume tends to diminish. The present findings tended to show a curvilinear relationship between heart rate and oxygen consumption until the maximal oxygen intake was reached. At this point, the heart rate continued to rise slightly while oxygen consumption declined (Figure 13). This observation is in agreement with Wahlund (38) who stated

that the linear relationship of pulse rate to oxygen consumption does not always exist at heavier work loads.

One possible explanation for the decline in oxygen consumption when the pulse rate is at approximately 180 beats per minute is that, no further increase in cardiac output would be expected in view of the short diastolic filling period. The oxygen for the working muscles may still be supplied by increased utilization but this is only possible for a short period of time under maximal conditions. Therefore, as the heart rate increases above its maximal effective rate, the diastolic filling time decreases as does the stroke volume and cardiac output. Consequently the supply of oxygenated blood flowing to the working muscles is decreased as is the oxygen consumption (7,38).

A second physiological explanation for the decline in oxygen intake at high heart rates deals with the arteriovenous oxygen difference in the blood. An increased heart rate would be accompanied by an increased rate of blood flow through the cardiovascular system which could be so rapid as not to permit sufficient time for the gas exchange to take place either at the "active tissue" level or in the lungs. Consequently, the oxygen supply to the working tissues would decline as would the amount of oxygen picked up from the lungs. Both of these factors would contribute to a decrease in the arterial-venous oxygen difference.

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CHAPTER V

SUMMARY AND CONCLUSIONS

It was the purpose of this study to investigate the relationship of maximal oxygen intake to total body weight, fat-free body weight and total body fat of individuals involved in a regular training regimen. The subsidiary problem was to investigate heart rate behavior in relation to the maximal oxygen intake.

Thirty male subjects at the University of Alberta, ranging in age from 19 to 34 years, participated in the study. All subjects had been taking part in regular physical activity a minimum of four days per week, one hour per day for at least one month. The subjects were tested for: a) maximal oxygen intake while running on a treadmill, b) body density by the hydrostatic weighing technique and c) total lung volumes by the helium dilution method. Test-retest reliability procedures were carried out for all measures. All determinations, including test-retest measures, were completed on individual subjects within a one week period. Body fat was calculated from the body density measurement, corrected for lung volume and gas in the gastro-intestinal tract, by the formula derived by Keys and Brozek (1:280). Heart rates were recorded during the maximal oxygen intake test, in conjunction with the collection of expired air.

The test data were analyzed by the "Stepwise Procedure for Multiple Regression" as described by Efroymson (2) which

included inter-correlation of all measures, calculation of single regression equations, calculation of the multiple regression equation and calculation of the multiple correlation coefficients. The *t* ratio for N-n-1 degrees of freedom provided a test to determine if the beta coefficient computed for each variable was significantly different from zero. The *F* ratio provided the test of significance for the multiple correlation coefficients.

Within the limitations of this study, the following conclusions were made.

1. The fat-free body weight correlated $r = 0.39$ with the maximal oxygen intake in physically active males. This correlation was statistically significant at the .05 level of confidence. Other measures of body mass and body composition did not show a statistically significant relationship with maximal oxygen intake in physically active males.
2. The fat-free body weight accounted for 15.76 per cent of the total variance of the maximal oxygen intake in physically active males which was considerably lower than the results reported by other studies using sedentary males.
3. The fat-free body weight is logically and practically the most satisfactory metabolic reference standard for the maximal oxygen intake of those that were investigated. With individuals in a highly active

state, the role of the fat-free body as an important determinant of maximal oxygen intake appears to be diminished.

4. A multiple correlation of 0.531 (statistically significant at the .05 level of confidence) between the three measures of body mass and body composition and the maximal oxygen intake was reported. This indicated that, in terms of prediction with active males, a more satisfactory estimate of the maximal oxygen intake would result from the inclusion of the fat-free body weight, total body fat and total body weight, instead of the fat-free body weight alone.
5. A rigid interpretation of results using the formula of Keys and Brozek (1:280) for per cent body fat estimates, is apparently limited in studies involving highly trained subjects.
6. The heart rate and oxygen intake were curvilinearly related until maximal oxygen intake was reached, at which time, the heart rate continued to rise while the oxygen consumption declined.

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APPENDIX A

STATISTICAL TREATMENT

STATISTICAL TREATMENT

Reliability of the Tests. Reliability coefficients, obtained by use of Pearson's Product - Moment correlation coefficient (1:143), were computed from the test-retest results. The formula used was:

$$r = \frac{N\Sigma XY - \Sigma X \cdot \Sigma Y}{\sqrt{\left[N\Sigma X^2 - (\Sigma X)^2\right]\left[N\Sigma Y^2 - (\Sigma Y)^2\right]}}$$

where X = test score
Y = retest score

The standard error of estimate for the reliability coefficients were calculated from the formula:

$$S_{xx'} = S_{x'}\sqrt{1 - r}$$

Multiple Regression - Stepwise Procedure. The multiple regression is used in data analysis to obtain the best "fit" of a set of observations of independent and dependent variables by an equation of the form (2:191):

$$y = b_o + b_1x_1 + b_2x_2 \ldots\ldots b_nx_n$$

where y = the dependent variable
$x_1x_2\ldots$ = the independent variables
$b_ob_1\ldots$ = the coefficients to be determined

In the stepwise procedure intermediate regression equations, are obtained by adding one variable at a time. These intermediate equations are not recorded by normal calculation methods. The variable addid is that one which makes the greatest improvement in "goodness of fit".

a) Single Regression Equation (3:99 - 106)

$$\hat{Y} = a_{y.x} + b_{y.x} X$$

where X = independent variable
Y = dependent variable

This is the method of least squares for fitting a line to a set of points and enables prediction of Y from X. The quantity a is a constant and is the distance on the Y axis from the origin to the point where the line cuts the Y axis. The quantity b is the slope of the line which is the ratio of the distance in a vertical direction to the distance in a horizontal direction. The values for a and b may be calculated by the formules:

$$b_{y.x} = r\frac{S_y}{S_x}$$

where S = standard deviation

$$a_{y.x} = \bar{Y} - b_{y.x} \bar{X}$$

The standard error of estimate for the regression equation is calculated from the formula:

$$S_{y.x} = S_y \sqrt{1 - r^2_{y.x}}$$

b) t Ratio. The $\pm$ ratio was used to test the significance of the beta coefficients in the regression equations.

$$t = \frac{\text{Beta Wt.}}{\sqrt{\text{Se of Beta Wt.}}}$$

df = N-n-1

c) Multiple Correlation. The multiple correlation coefficients were obtained from the formula:

$$R = b_2r_{12} + b_3r_{13} \dots b_nr_{1n}$$

That is, we multiply each correlation of a predictor with the criterion by its corresponding regression coefficient, sum these products and take the square root.

d) F Ratio. The F ratio was used to test whether an observed multiple correlation coefficient was significantly different from zero. The required value of F is given by the formula:

$$F = \frac{R^2}{1-R^2} \cdot \frac{N-k-1}{k}$$

where R = multiple correlation coeficient
N = number of observations
k = number of independent variables

The table F is entered with $df_1 = k$ and $df_2 = N-k-1$.

REFERENCES

1. Garrett, H enry E., _Statistics in Psychology and Education_, 5th, edition, New York: Longmans, Green and Co., 1959.

2. Efroymson, N.A., "Multiple Regression Analysis" in _Mathematical Methods for Digital Computers_, edited by A. Ralston and H.S. Wilf. New York: John Wiley and Sons, Inc., 1960, pp. 191-204.

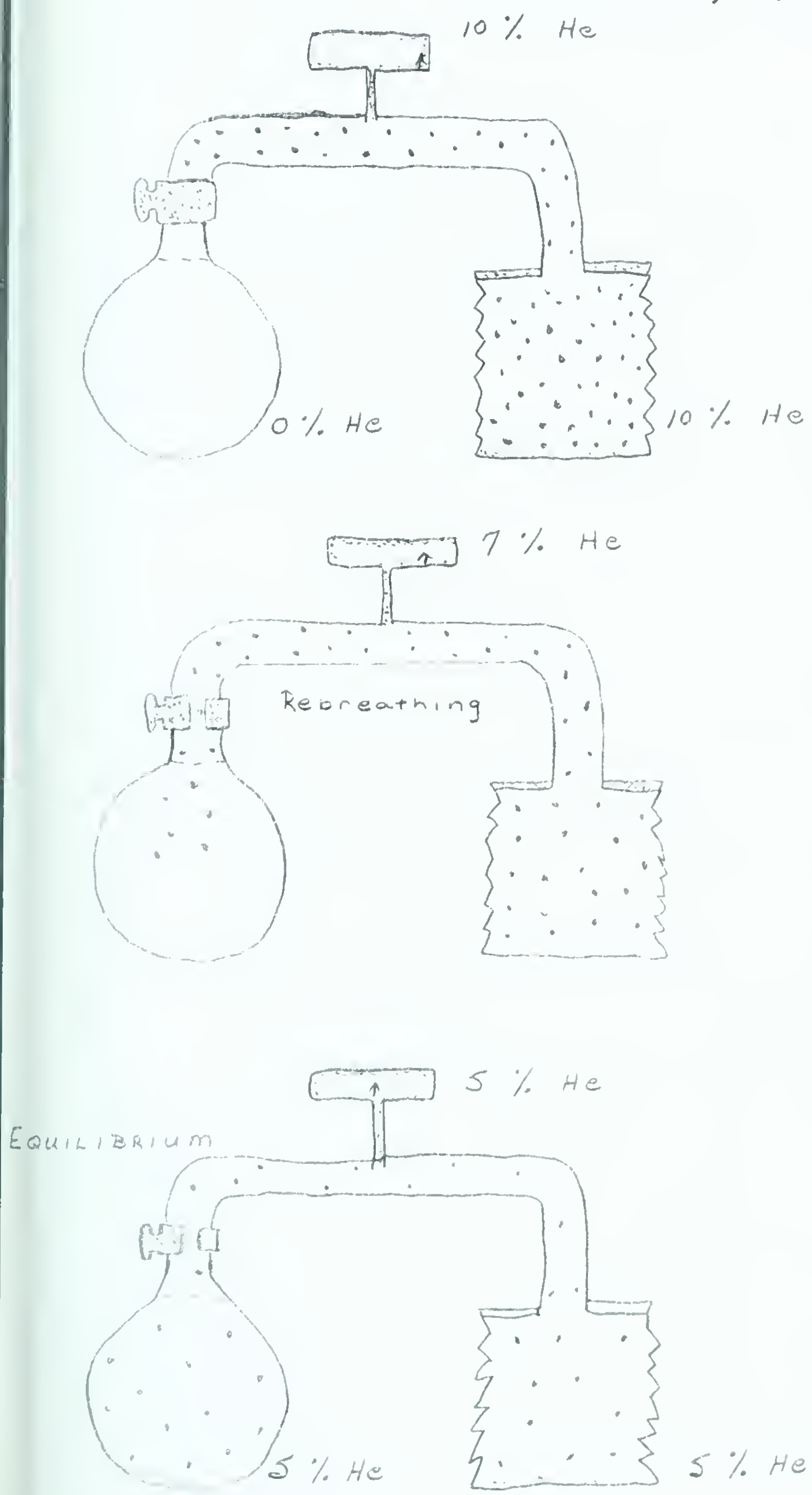
3. Ferguson, George A., _Statistical Analysis in Psychology and Education_. New York: McGraw-Hill Book Company Inc., 1959.

APPENDIX B

HELIUM DILUTION METHOD

HELIUM DILUTION DETERMINATION OF LUNG VOLUMES - CLOSED CIRCUIT METHOD

Reference: Comroe, J.H., Foster, R.E., Dubois, A.B., Briscol, W.A., Carken, E., The Lung - Clinical, Physiologic and Pulmonary Function Tests. Chicago Yearbook Publishers, 1955, pp. 15-17.



The principle of the closed circuit technique is shown in the accompanying figure. In each case the bellows represent a spirometer, bellows or bag in the closed circuit. The unknown in each case is the volume of the lungs: the initial volume of the bellows is known and the initial concentration of Helium is known for both the lungs and the bellows. The initial concentration of helium in the lungs is zero and in the bellows is precisely 10 per cent (a known value of helium being added to the bellows before starting the test.) The subject then rebreathes from the bellows until mixing is complete, i.e., the concentration of Helium is the same in both the lung and the bellows.

The initial volume of gas in the

lungs is then computed on the principle that the number of molecules of helium is the same in the lung-bellows system at the end of the test as at the beginning. Thus:

Amount of He in lungs + amount of He in bellows = total amount of He. Amount of He = volume of gas (v) X fractional concentration of helium (F) .

Therefore:

$V_L F_L$	+	$V_B F_B$	=	$(V_L + V_B)\ F_L$
(<u>initial</u> lung)		(<u>initial</u> bellows)		(<u>end</u> lung + bellows)

If the volume of the lungs is unknown and the volume of the bellows is 2,000 ml., and the initial and final concentrations in the bellows are 10 per cent and 5 per cent respectively:

$$0 + (2000 \times 0.10) = (V_L + 2000)\ 0.05$$

$$200 - 100 = 0.05\ V_L$$

$$V_L = 2000 \text{ ml.}$$

Residual Volume = Total Lung Capacity - Vital Capacity (if the test began with the subject at full inspiration)

<u>or</u>

R.V. = functional residual capacity - expiratory reserve volume (if the subject is breathing at the "more constant" resting expiratory level).

APPENDIX C

RAW SCORES

Subject	Age	Weight (kgs.)	Height (in.)	Fat (kg.)	Fat-Free (wt.kg.)	% Fat
1	34	67.8	67	04.2	63.6	.062
2	25	69.6	68	03.8	65.8	.055
3	21	84.3	73	01.3	83.1	.015
4	20	68.9	70	04.5	64.3	.066
5	22	67.5	67.5	03.9	63.6	.058
6	24	68.1	70.5	00.5	67.6	.008
7	26	76.3	73.5	05.9	70.4	.077
8	21	73.1	71	00.4	72.7	.005
9	23	88.1	73	07.7	80.4	.087
10	20	82.5	75	03.4	79.1	.041
11	22	64.5	69	00.8	63.6	.013
12	22	86.0	72	06.0	80.0	.070
13	34	59.5	66.5	01.3	58.2	.022
14	19	76.0	72	00.0	76.0	.000
15	19	69.5	68.5	03.8	65.6	.055
16	19	77.9	76	02.7	75.3	.034
17	19	72.9	68.5	01.2	71.8	.016
18	34	82.6	69.5	12.4	70.2	.150
19	30	74.0	73	00.0	74.0	.000
20	22	68.5	67.5	00.7	67.9	.010
21	22	76.0	70.5	01.5	74.5	.020
22	23	69.0	68	03.5	65.6	.050
23	21	75.4	73	00.0	75.4	.000
24	18	76.3	72	01.2	75.0	.016
25	22	73.1	70	01.2	71.9	.016
26	22	71.5	73	02.3	69.2	.032
27	23	86.9	73	05.2	81.7	.060
28	22	83.9	68	03.4	80.5	.041
29	23	80.1	73	05.0	75.2	.062
30	21	81.7	75	01.3	80.4	.016

Subject	Lung Vol.L. #1	Lung Vol.L. #2	Max.O_2 Intake L./min.#1	Max.O_2 Intake L./min.#2	Max.O_2 c.c./Kg. Wt.	Max.H.R. Beats/min.
1	6.27	--	--	3.132	46.6	180
2	7.079	6.304	3.736	3.994	57.8	180
3	8.32	8.66	5.25	5.86	69.5	180
4	6.003	5.964	4.73	5.89	84.6	188
5	6.14	6.31	4.185	4.19	62.1	180
6	6.157	6.073	4.20	4.35	63.8	167
7	7.71	7.62	4.02	4.21	54.6	180
8	7.36	--	--	5.15	70.4	167
9	8.44	8.33	4.43	4.49	51.7	180
10	8.39	8.64	4.64	5.10	61.8	180
11	5.71	5.74	3.89	4.42	68.7	167
12	7.85	7.93	4.97	5.35	62.2	180
13	6.29	--	--	4.68	78.6	141
14	9.71	9.18	5.68	6.28	83.0	184
15	6.65	6.87	4.98	5.60	80.2	184
16	8.84	9.27	4.84	5.23	66.2	180
17	7.56	7.68	4.47	4.60	62.8	180
18	6.48	6.70	--	3.82	46.0	180
19	9.44	10.02	5.10	5.48	74.1	180
20	5.22	5.48	4.01	4.58	67.3	180
21	6.64	6.70	4.30	4.60	60.5	173
22	5.86	5.88	3.65	4.02	58.3	187
23	7.35	7.24	4.61	4.72	62.6	180
24	7.70	8.20	4.88	5.01	65.7	187
25	6.37	6.37	4.62	4.68	64.1	180
26	6.75	6.94	3.81	4.01	54.9	180
27	8.41	8.41	5.37	5.47	62.9	180
28	6.51	6.87	4.45	4.65	55.4	180
29	7.04	6.91	4.49	4.89	60.0	184
30	7.40	7.48	3.96	4.12	49.8	180

APPENDIX D

SAMPLE CALCULATION SHEETS

MEASUREMENT OF BODY COMPARTMENTS

Time ________. Name ______________________________ Age ____

Temp.________ ^{o}C. Date ______________ Study ________________

Water Temp.________ ^{o}C.

B.R. (mm. Hg)_______.

Water Density_______.

Densitometric Determination

1. Weight in Air (x) __________ lbs.
2. Apparent Weight in Water (full inspiration) (x) __________ lbs.
3. Weight of Apparatus (x) __________ lbs.
4. Submerged Weight = __________ lbs.
5. Total Gas Volume (T.L.C.) _____ + (V.G.I.)_____ = ________ cu.in.

   ______ cu.in. x .0362 = __________ lbs.
6. True Weight in Water (4.) ____ +(5.) ________ = __________ lbs.
7. Body Volume (1.) ____ -(6.) ________ =__________
8. Body Density $\frac{(1)}{(7)}$ ______ x (D. Water)_____ = _____

TOTAL BODY FAT

a) D = ____________. (table)

Total Fat = _____ or_____%

b) Fat Weight =(1.)_____ x (a)_____

= _________ lbs.

c) Fat Free Weight = (1)______

− (b)_______ = _________ lbs.

Verification of Lung Volumes (B.T.P.S.)

Land Vital Capacity = _____ l

Residual Volume __________.

Total Lung Cap. __________.

OXYGEN CONSUMPTION CALCULATION SHEET

NAME:________________________

DATE:________________________

t = ________ ^{o}C

B.P. = _________ mm. Hg.

Factor = _________

F_EO_2 = ____________ X $\frac{2.5}{1000}$ = ___________

F_IO_2 = 20.94

(corr.) F_EO_2 = ___________

F_ICO_2 = 00.03

F_IN_2 = 79.03

F_ECO_2 = _______________

F_EN_2 = ________________

V_EATPS = __________ l./min.

V_ESTPD = __________ x __________ = _________ l./min.

V_ISTPD = __________ x $\frac{\_\_\_\_\_\_\_\_\_\_}{.7903}$ = _________

VO_2 = (________ x 20.94) - (________ x _________) = _______ l./min.

HELIUM DILUTION METHOD FOR

MEASURING LUNG VOLUMES

Vital Capacity	V.C.	________ l.
Inspiratory Capacity	I.C.	________ l.
Expiratory Reserve Volume	E.R.V.	________ l.

<u>Formula for Functional Reserve Capacity</u> (F.R.C.)

$$V_L F_L + V_B F_B = (V_L + V_B)\, F_{LB} \quad \text{or}$$

$$V_L = \frac{V_B(F_B - F_{LB})}{- F_{LB}}$$

Where:

V_L = lung volume desired (F.R.C.)

F_L = initial He concentration in lungs (=0)

V_B = volume of spirometer (=10.1 liters)

F_B = initial He concentration in spirometer

F_{LB} = final He concentration in spirometer and Lungs

<u>Calculation of F.R.C.</u>

(1) Initial value of He (F_B) ________ %

(2) Final value of He (F_{LB}) – ________ %

(3) ________ × 10.1 = ______ l.

(4) F.R.C. = $\frac{(3)}{(2)}$ ________ = ________ l.

(5) Residual Volume R.V. = F.R.C. – E.R.C. = ______ – ________ = ________ l.

(6) Total Lung Capacity T.L.C. = V.C. + R.V. = ______ + ______ = ________ l.